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The mobile emergency winder supplied by The English Electric Company to the National Coal Board for service in the Northern (Northumberland and Cumberland) Division

Mobile Emergency Winders

THE form of winder described in this article originated for Civil Defence purposes, but such winders are now recognised as being as essential a part of mine rescue equipment as breathing apparatus. Strategically located, speedy and efficient emergency, standby or maintenance service can be rendered to a number of collieries.

Two of these mobile emergency winding equipments have been supplied by The English Electric Company to the National Coal Board for use in Northern (N. & C.) and Durham Divisions. Their required duty is to sustain a rope end load of 2 tons at a maximum speed of 8 feet per second for winding depths of up to 3,000 feet.

The typical equipment shown in Fig. 1 is a self-contained unit comprising a towing vehicle on which is mounted a diesel engine driving main and auxiliary D.C. generators forming the power source, and a trailer carrying the winder together with the associated mechanical and electrical control gear. Also mounted on the trailer is a portable telephone and signalling communication system.

General Particulars

Mechanical Details

Drum diameter	4 ft 0 in
Drum width	3 ft 0 in
Type of rope	Locked coil
Diameter of rope	$\frac{5}{8}$ in
Weight of rope	1 lb/ft
Layers of rope	5
Maximum speed of drum	37.5 r.p.m.
Gears	Double reduction 26.6/1 overall : first reduction double helical, second reduction straight cut
Brakes	Drum : oil pressure operated. Pinion shaft : weight operated

Duty cycle diagrams for 750, 1,500 and 3,000 ft are given in Figs. 2 and 3.

Winder Motor

R.M.S. rating	95 h.p. ± 0/1,000 r.p.m. ± 0/320 volts
Peak rating	150 h.p.
Frame	CAM 152/48
B.S. Spec.	168:1936. Class B insulation
Enclosure	Drip proof, canopy protected, louvre ventilated
Type	Two oil-ring lubricated journal bearings in endshield, with tapered shaft extension and flexible coupling
Field	Shunt wound. Separately excited from 110 volts

Main Generator

Continuous output	78 kW 1,250 r.p.m. ± 0/320 volts
Peak output	127 kW
Frame	CAM 152
B.S. Spec.	168:1936. Class B insulation
Enclosure	Drip proof, canopy protected, louvre ventilated
Type	One oil-ring lubricated journal bearing in endshield at non-driving end, with shaft extension carrying V rope pulley for exciter drive. Shaft extension at driving end for coupling to diesel engine flywheel
Field	Shunt wound. Separately excited from 110 volts with small reverse series winding

Auxiliary Generator

Output	4 kW 1,750 r.p.m. 110 volts

Frame	ACB.6
B.S. Spec.	168:1936. Class B insulation
Enclosure	Drip proof, canopy protected
Type	Two oil-ring lubricated journal bearings in endshield, with shaft extension carrying V rope pulley at driven end
Field	Level compound

Diesel Engine

Rated output	195 b.h.p. 1,250 r.p.m.
Overload	10% for one hour
Size	6 H
B.S. Spec.	649
Type	Six-cylinder 4-stroke, naturally aspirated, mechanical injection, pressure lubricated, cold starting, totally enclosed
Bore	6 inches
Stroke	8 inches
Starting	24-volt starter motor and batteries, and Bryce Berger hydraulic system
Cooling	Forced draught cooled radiator for both circulating water and lubricating oil
Fuel tank	Five-hour supply replenished by hand-operated transfer pump from external supply

Control

From the schematic diagram in Fig. 4 it will be seen that the winder motor is controlled by the well-known Ward Leonard system, in which, with maintained field, the speed of the winder motor is adjusted by varying the voltage applied to the armature. The voltage variation is obtained by varying the field current of the generator through the medium of a rheostat which is manually operated by the driver. Change in direction of rotation of the winder motor is effected by reversing the polarity of the applied armature voltage, the rheostat being bi-directional. Contacts forming the master controller are operated from the drive shaft of the rheostat. When the motor is at rest, with the mechanical brake applied and the driver's rheostat in the 'off' position, it is necessary to limit the current in the main loop in order to protect the motor and generator armatures. This is achieved by disconnecting the generator field from the driver's rheostat circuit and reconnecting it directly across the generator armature in polarity opposition, a method of killing the generator field usually known as 'suiciding'. A discharge resistance is paralleled with the generator field in order to limit the induced voltage to a safe value when the field is suddenly disconnected from the rheostat circuit in the event of an emergency trip.

Protection

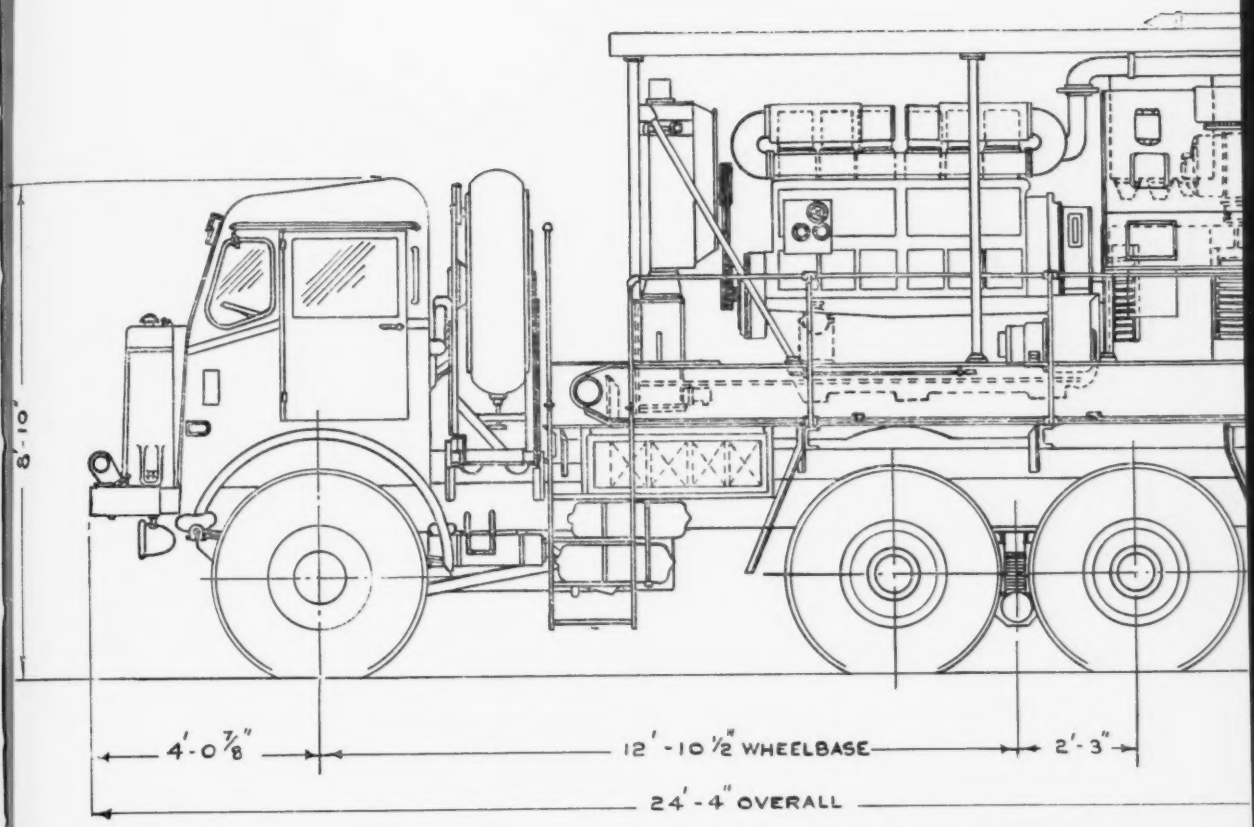
All protection is centred upon the operation of the brake solenoid contactor in the safety circuit, which opens upon interruption of its coil circuit by the operation of any of the series-connected safety contacts, e.g., overspeed, overwind, driver's emergency stop. The opening of the brake solenoid contactor removes the supply from the winder motor and generator fields, suicide contactor coil and brake solenoid. De-energising the brake solenoid results in automatic application of the mechanical brake.

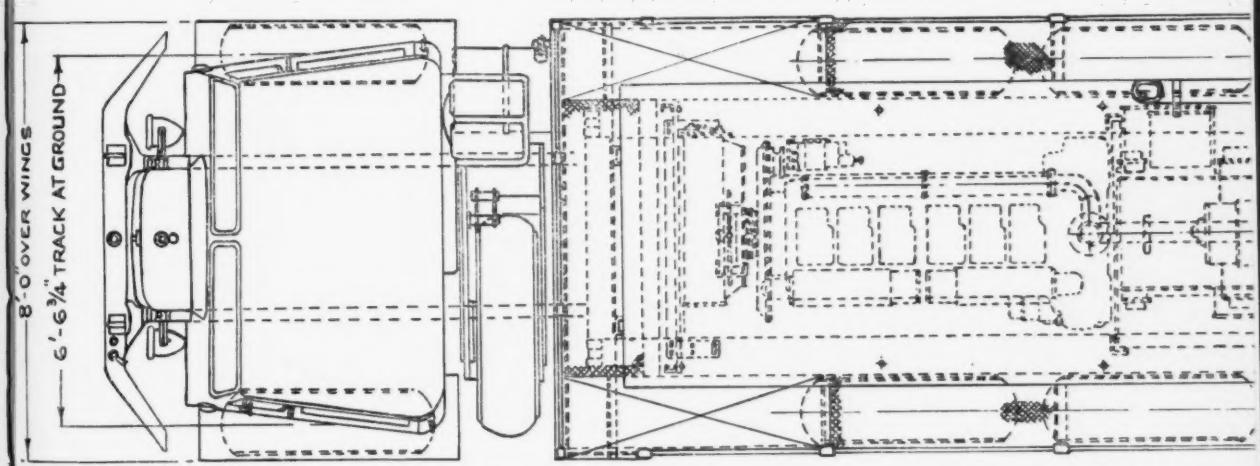
Short-circuit protection of the machines is afforded by H.R.C. fuses in the main loop and in the supply from the auxiliary generator. Should the operation of a fuse remove the supply from the winder motor when lowering a load, overspeed protection is provided by a winder-driven mechanical overspeed device which opens the brake solenoid contactor.

Overcurrent protection is obtained from a current relay in the main loop which, when operated, interrupts the supply to the brake solenoid contactor.

Safety Interlocks

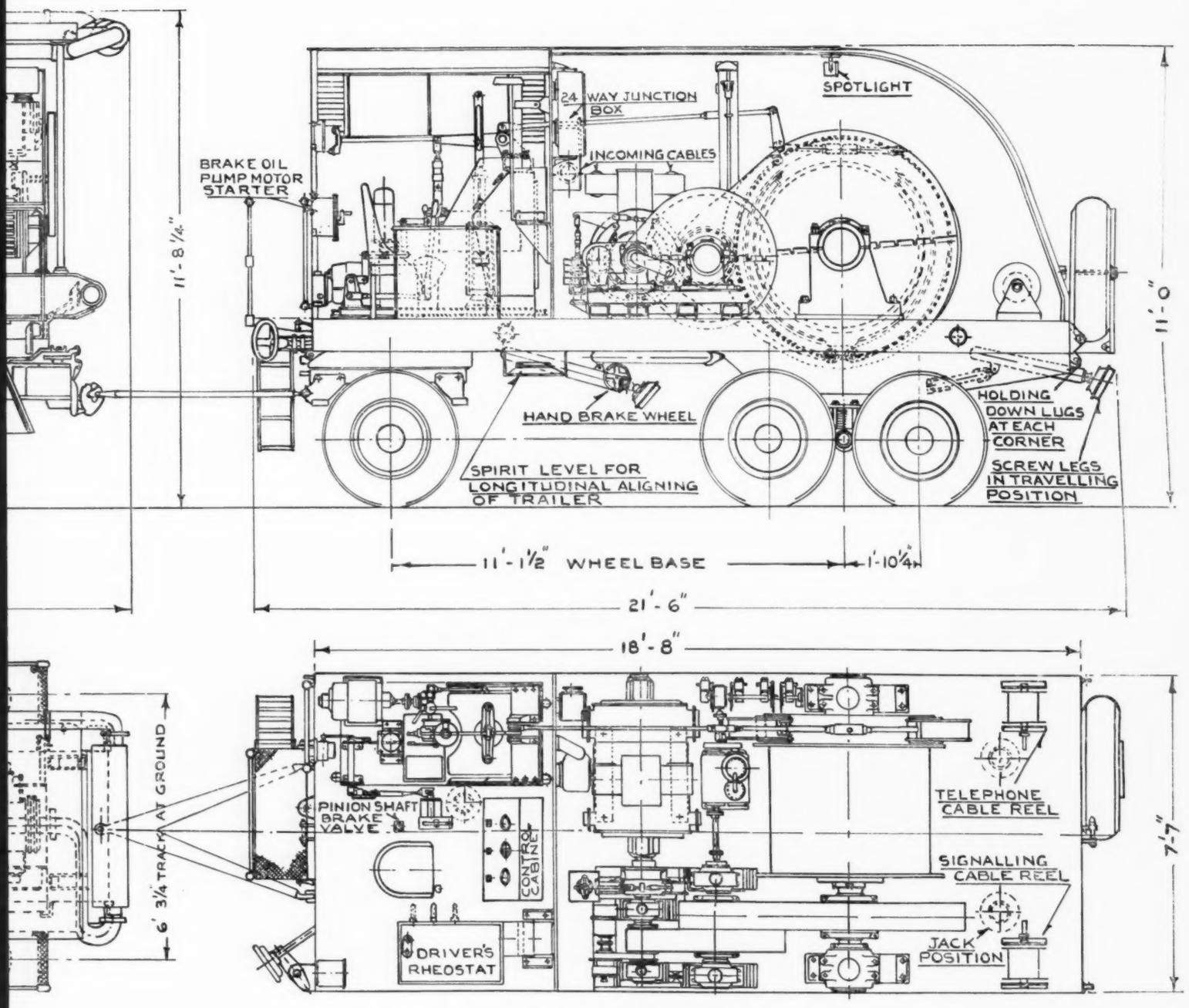
An 'off-position' interlock circuit is provided to ensure that the driver's rheostat is in the 'off' position and the mechanical brake applied before





GROSS WEIGHT 17½ TONS

Fig. 1.–



GROSS WEIGHT 18 TONS

General arrangement of mobile winder

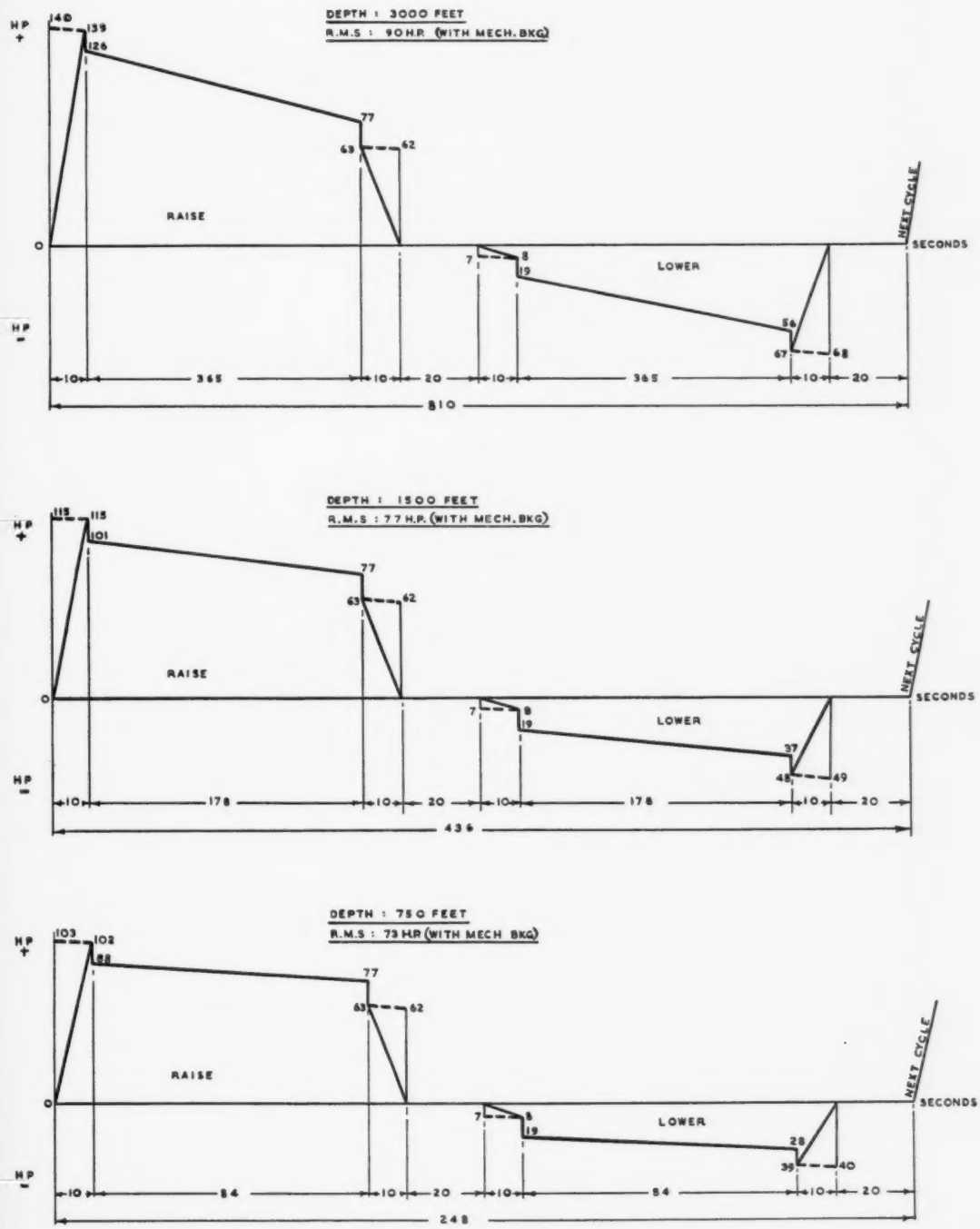


Fig. 2.—Duty cycle diagram for raising full conveyance and lowering empty conveyance

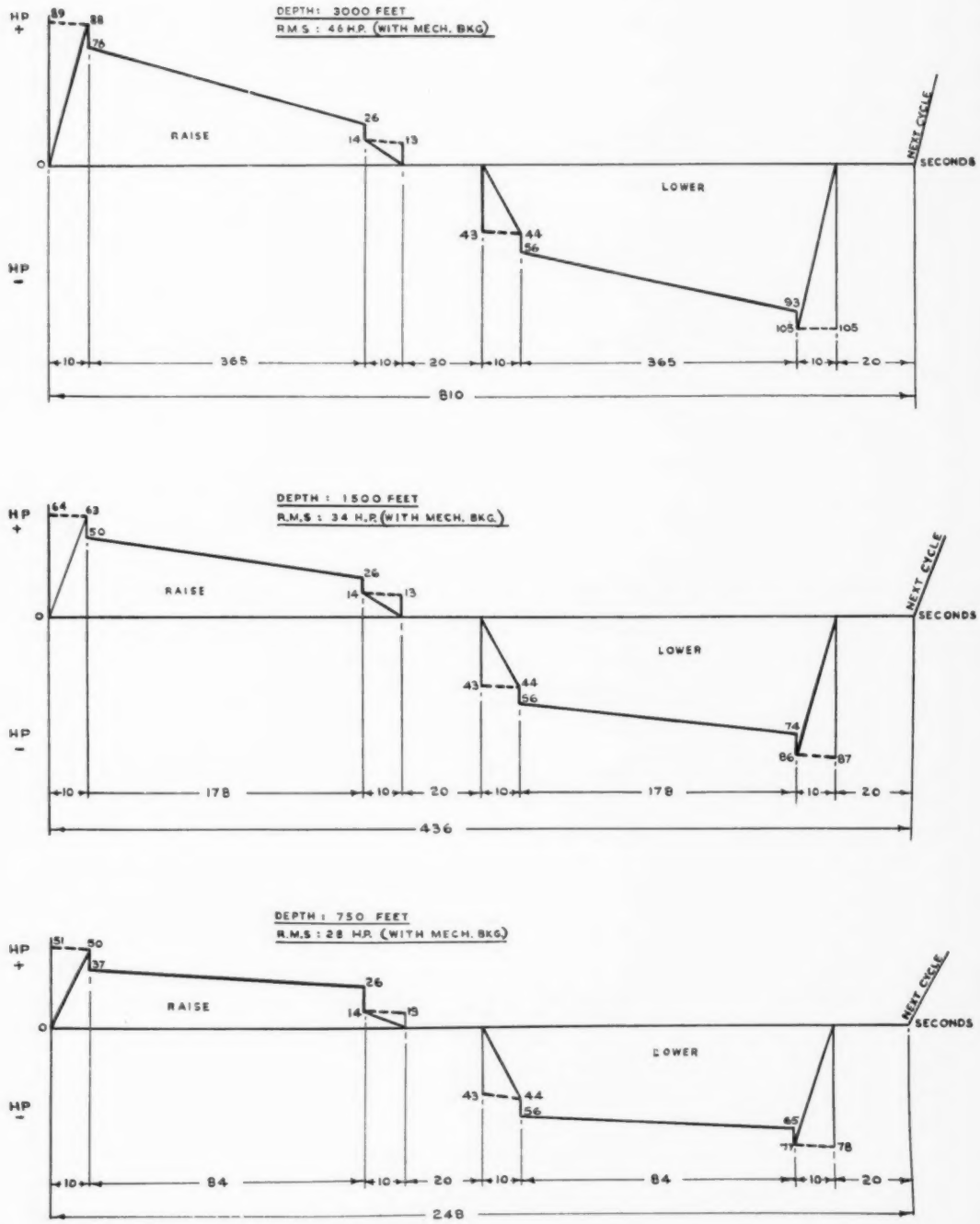


Fig. 3.—Duty cycle diagram for raising empty conveyance and lowering full conveyance

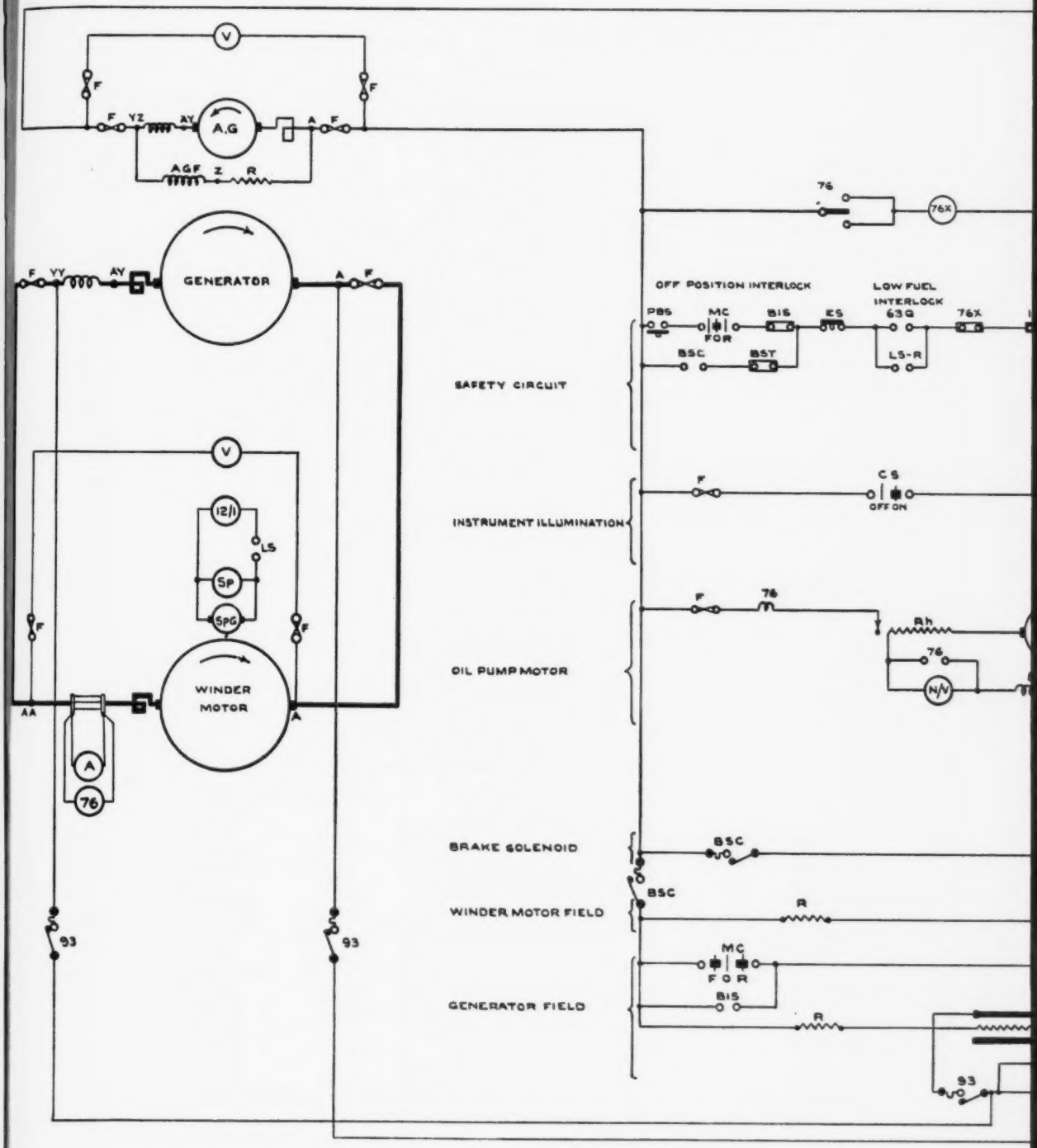
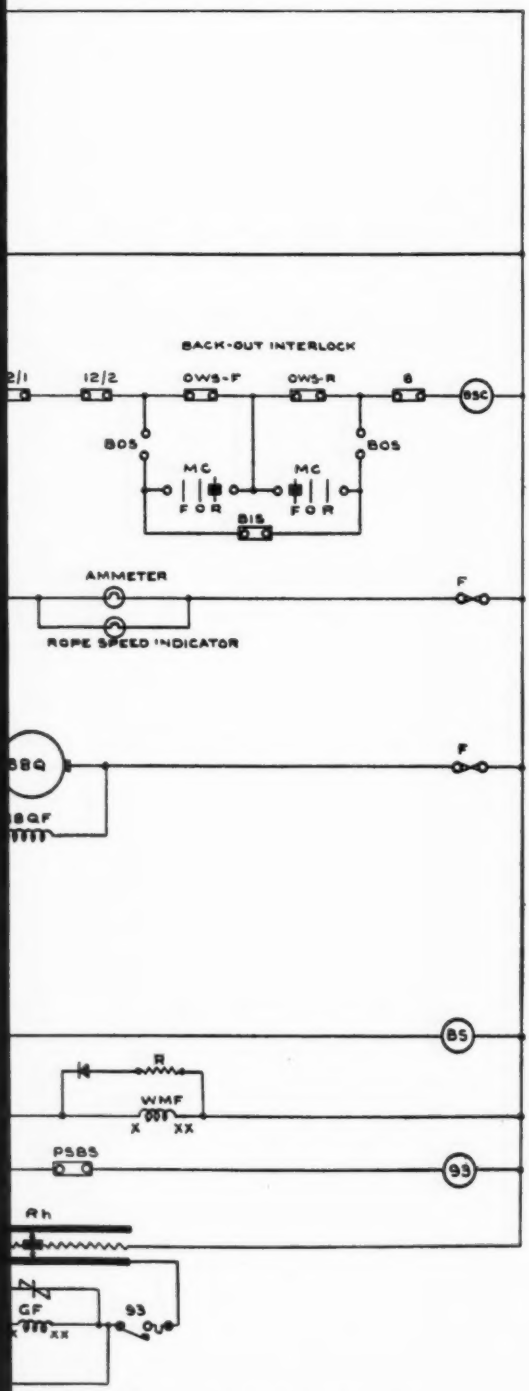


Fig. 4—Schematic diagram of electrical circuits for the operation



, control and safety interlocking of a mobile winder

Abbreviations.

8	Isolating switch
12/1	Overspeed relay
12/2	Winder driven overspeed switch
63Q	Float switch for diesel fuel oil low level
76	Overcurrent relay
76X	Auxiliary relay for 76
88Q	Oil pump motor
88QF	Oil pump motor field
93	Generator field contactor
A	Ammeter
AG	Auxiliary generator
AGF	Auxiliary generator field
BS	Brake solenoid
BIS	Brake interlock switch
BOS	Back-out switch
BSC	Brake solenoid contactor
BST	Brake solenoid trip switch
CS	Control switch
ES	Emergency stop switch
F	Fuse
GF	Generator field
LS	Landing speed limit switch closes one drum revolution from end of forward wind
LS-R	Limit switch—surface open when conveyance at surface
MC	Master controller. F-forward. O-off. R-reverse
NV	No-volt trip coil
OWS-F	Overwind switch—forward
OWS-R	Overwind switch—reverse
PBS	Reset push-button switch
PSBS	Pinion shaft brake switch
R	Resistance
Rh	Rheostat
Sp	Rope speed indicator
SpG	Rope speed indicator generator
V	Voltmeter
WMF	Winder motor field

Master controller contact closed in off position

the brake solenoid contactor coil can be energised via the driver's re-set push button, assuming that the remainder of the safety circuit is healthy. Closure of the brake solenoid contactor completes a retaining circuit to maintain the safety circuit upon release of the driver's re-set push button.

To maintain the diesel oil fuel supply at a safe level, a float switch in the fuel tank is provided with a pair of contacts connected in the safety circuit and so arranged that in the event of low fuel level they open the circuit only when the conveyance is at the surface. Under these conditions prior warning is given by an audible and/or visible alarm operated by second pair of contacts on the float switch.

Overwind protection is afforded by two cam-operated winder-driven switches, one for each end of the wind, arranged to open the safety circuit in the event of travel of the conveyance beyond these limits. Should, for example, the conveyance travel beyond the shaft bottom limit, the forward limit switch opens the safety circuit. In order to ' back-out ' of the overtravel, the driver's master controller must be returned to the ' off ' position, the mechanical brake fully applied, the foot-operated backing-out switch closed and the safety circuit restored by operation of the re-set push button. With the backing-out switch held closed, the overtravel is cancelled by movement of the master controller in the ' reverse ' direction only, the mechanical brake being released as the motor torque is increased to raise the conveyance. When the conveyance has been brought inside the limit, the backing-out switch is released and the limit switch is automatically re-set. Should the master controller be moved inadvertently to the ' forward ' position, the safety circuit will be opened immediately upon release of the mechanical brake. The converse will apply when the surface limit is exceeded.

In order to meet a requirement that the landing speed when approaching the shaft bottom shall not exceed 5 feet per second, a voltage relay is provided with contacts connected in the safety circuit. A winder-driven D.C. tachometer generator is connected to the voltage relay coil via a winder-driven cam-operated limit switch arranged to be closed only during the last revolution of the drum before reaching the shaft bottom. Failure to observe this speed limitation results in opening the safety circuit.

Towing Vehicle

The towing vehicle (Fig. 5) is driven by an 11.3 litre 6-cylinder direct injection oil engine transmitting power through a 5-speed gearbox and 2-speed auxiliary gear to a fully articulated double reduction double drive rear bogie with a 7.9/1 axle ratio, and to a fully floating double reduction front axle. A power take-off drives a 7-ton winch, the rope from which can be arranged for use at the front or the rear of the vehicle. An air pressure braking system incorporating a twin cylinder compressor is used to operate the wheel brakes of both vehicle and trailer. The system provides facilities for inflation of all tyres.

The diesel engine and generators forming the power source for the winder are mounted on a skid base bolted to the towing vehicle chassis and, dependent upon site conditions, may be operated on or off the vehicle as required. When mounted on the vehicle, ample access to the power unit is provided by a platform surrounding three sides.

The output from the main and auxiliary generators is taken to a fuse box equipped with two mining flit-type adaptors to receive positive and negative main cable boxes, and also a mining-type socket to receive a twin core auxiliary cable. A junction box mounted on the opposite side of the fuse box is fitted with a mining-type socket to receive a multi-core control circuit cable.

Trailer

The chassis of the trailer (Fig. 6) is constructed for movement on the road or on standard gauge railway lines, as required by site conditions, and is carried on three spring-mounted axles. Six pneumatic-tyred wheels are provided for road use ; these when removed expose steel wheels for rail use, the middle pair of which is not flanged in order to assist negotiation of acute bends commonly encountered in colliery sidings. The leading axle is carried on a turntable which is fitted with hand steering mechanism operated through a worm reduction gear by a handwheel from the side of the trailer. This feature in conjunction with a hand

Fig. 5.—Two views of the towing vehicle carrying the diesel engine and generators providing the power for the winder

Fig. 6.—The trailer containing the winder and associated mechanical and electrical control gear

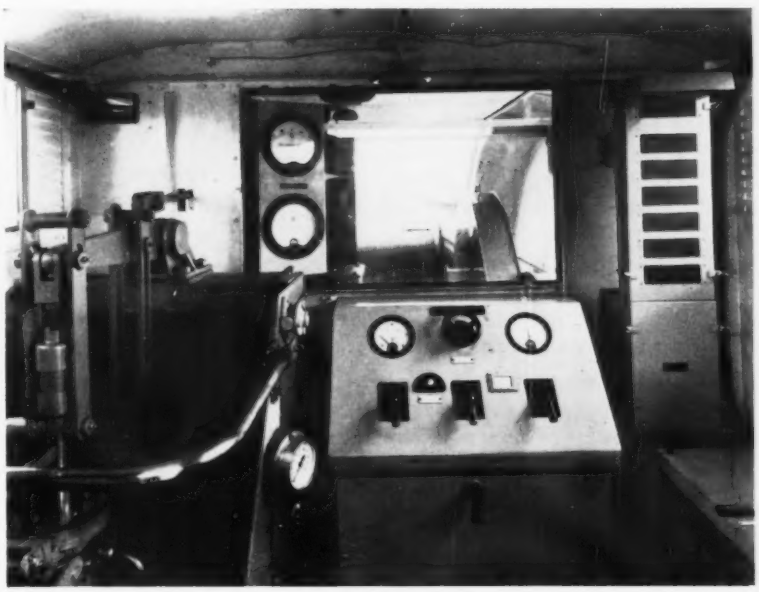


Fig. 7.—The control cabin in the trailer

Fig. 8.—Winding drum and driving motor, with control cabin in background

operated winch at the rear of the vehicle is invaluable when positioning the equipment in limited manoeuvring space where the towing vehicle cannot be used. When the trailer is road hauled the hand steering mechanism is rendered inoperative, and movement of the turntable is governed by that of the drawbar. When the trailer is in use on colliery sidings the turntable is locked and the vehicle connected by a separate towing bar attached to a special coupling on the chassis.

In the absence of the towing vehicle, brake control is effected by a handwheel located on the near side of the chassis. When the winder is in use, the road wheels and springs are relieved of all operational forces by supporting the chassis on three spherically seated screw jacks which are hinged and secured to the underside of the chassis when not required. The jacks also serve to align the chassis horizontally with the aid of built-in precision spirit levels. When desired, rigid location can be provided in service by anchoring the four corners of the chassis to a pre-sited concrete foundation by means of flexible ropes fitted with turnbuckles.

The control cabin (Fig. 7) is located at the forward end of the vehicle and positioned to afford unrestricted views of depth indicator, drum and pit top. Back and fore sights are provided to facilitate alignment of winding drum (Fig. 8) with headsheave. The control cabin houses the control cabinet, combined rheostat and master controller, signal indicator and relays, telephone, and oil pressure brake unit.

The brake unit of the winder (Fig. 9) consists of a motor driven oil pump which charges an accumulator providing constant pressure to the top of a double acting brake engine in the direction of 'brakes on', the pressure also raising the safety weights to the 'off' position. The brakes are released by the driver's brake lever moving the control valve to admit pressure to the bottom of the brake engine, and are applied

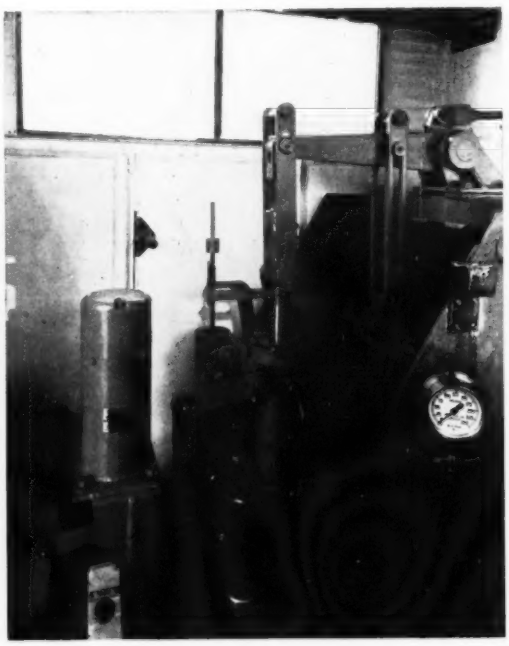


Fig. 9.—Oil-pressure brake unit

by operating the control valve to release pressure from the bottom of the engine to exhaust, constant pressure remaining on the top of the engine. In the event of an emergency trip, the fall of the plunger of the de-energised brake solenoid opens the control valve to exhaust to apply the brake. The safety weights only operate to apply the brake when there is a partial or complete failure of oil pressure. In the former case the weights commence to fall to reinforce the lowered pressure, and in the latter case they fall immediately.

A weight-operated secondary brake is fitted to the pinion shaft ; it is held ' off ' by oil pressure from the main brake system, and applied by manual operation of a pressure release valve. Application of the brake removes power from the motor and ' suicides ' the generator field. The purpose of this brake is to afford protection in the event of failure of any of the electrical tripping devices, or mechanical failure of the main linkages to the drum brake. Loss of oil pressure results in automatic application of the pinion shaft brake.

A vertical type of depth indicator, gear driven from the drum, indicates by means of a travelling pointer the position of the conveyance in the shaft. The gearbox is arranged for hand selection of one of three ratios in order to obtain maximum movement of the pointer for depths of 750, 1,500 or 3,000 feet respectively.

Acknowledgment

The courtesy of the Northern (N & C) and Durham Divisions of the National Coal Board is acknowledged concerning the description and illustrations of the mobile winders published in this article.

Sub-Contractors

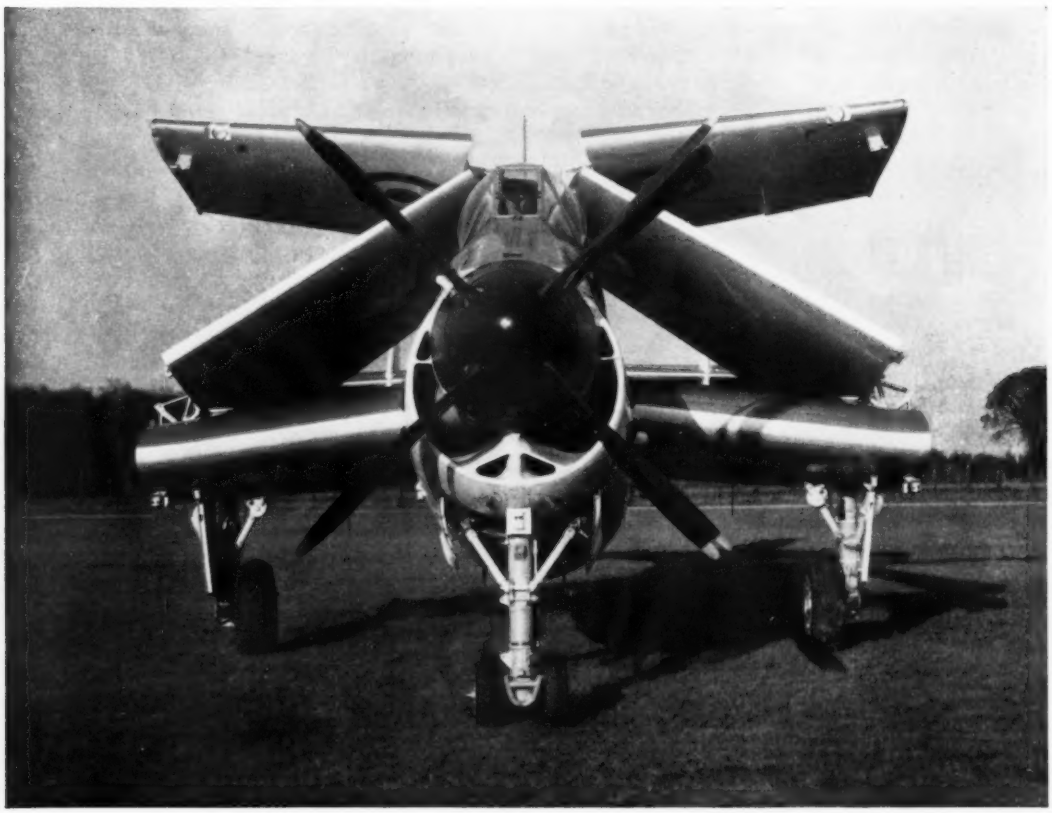
As sub-contractors to The English Electric Company for the two mobile winders supplied to the Northern (N & C) and Durham Divisions of the National Coal Board, Robey & Co. Ltd., Lincoln, supplied the mechanical parts, and A.C.V. Sales Ltd., and Leyland Motors Ltd. the towing vehicle chassis.

Napier Spraymat De-icing System on the Fairey Gannet

THE FLIGHT DEVELOPMENT ESTABLISHMENT of D. Napier & Son Limited is installing the Napier 'Spraymat' De-icing System* on the Fairey Gannet anti-submarine aircraft. This aircraft is powered by an Armstrong Siddeley 'Double Mamba' propeller turbine engine, the main air intake of which will be protected from ice formation by the Napier Spraymat electric surface heater.

The Napier system was selected as being the only practical method of protecting the very complicated air intake of the Gannet. The intake consists of two half sections, the main scoops each feeding air to one of the coupled Mamba engines, whilst air for the engine oil coolers is supplied through the

* *Described in E. E. Journal, December* 1954, *Vol.* 13, *No.* 8, *p.* 353.



A Fairey Gannet anti-submarine aircraft with wings folded

opening below them. When flying in icing conditions it is necessary to heat continuously the leading edges and inner surfaces of the whole assembly to prevent ice formation from either blocking the small ducts or entering the main engine air intakes. The application in this case is therefore 'anti-icing', as ice entering the engine could possibly result in serious damage.

The Napier Spraymat heater consists of three layers sprayed one after the other on to the metal intake, forming a metallic electrical element embedded between two insulating layers. It is thus ideal for the intricate curvatures of the intake surfaces which make it difficult to maintain accurate contours from one part to another. The outer surface insulation of the Gannet's heater is pigmented during manufacture to produce an aluminium finish which blends perfectly with the aircraft's general painting scheme.

The Gannet's heater is designed to operate from a 208 volt A.C. 3-phase supply at 400 c.p.s., and provides a graded heat output from 9.6 watts/sq. in. at the leading edges to 4.5 watts/sq. in. inside the intake, the total power requirements being 7.38 kW. The flexibility of operation of the Spraymat heater is demonstrated by the fact that it can be connected up in the following three different ways to produce the same standard of ice protection:—

(*a*) The whole intake operated on a single-phase supply (single-phase connection).

(*b*) Each half-section of the intake operated on a separate phase (two-phase connection).

(*c*) The whole intake operated on a three-phase supply, one phase to each half-section and the third phase passing through a proportion of both half-sections connected in series (three-phase connection).

On the present Gannet aircraft installation, scheme (*a*) is used, the load being balanced by the other phases supplying the spokes of the air intake and the engine-inlet guide vanes respectively.

'Spraymat' can stand up to quite severe maltreatment without its serviceability being affected, as the materials used in its construction are flexible, tough and highly resistant to abrasion. Serious mechanical damage is easily repairable by a grafting process in which the damaged area is removed and a new section of heater mat is sprayed on to restore the system to its original condition.

During the winter of 1952/3, the first prototype heater successfully underwent full 'winterisation' trials at the engine laboratory of the Canadian National Aeronautical Establishment, whilst a second prototype was subjected to a 50-hour functional test at the Napier Flight Development Establishment at Luton. Full instrumentation was provided for both prototypes, half of each intake being fitted with 25 thermo-couples to record the performance of the heater whilst under test. After a period of further development, one of the first production type heaters underwent a comprehensive ground and flight test programme carried out by the Fairey Aviation Company Limited at White Waltham aerodrome. These tests included the operation of the anti-icing heaters at full power during prolonged ground running of one or both engines, taxying and during the glide approach to landing. The Spraymat proved capable of withstanding the elevated surface temperatures produced as a result of the relatively low air flows through the intake and correspondingly reduced cooling effect. A second production heater recently completed a 150-hour type test on the Armstrong Siddeley engine test beds.

Squadrons of the Fleet Air Arm are now being equipped with the Gannet to serve as both a carrier and shore based anti-submarine patrol aircraft. A number of these aircraft are also being supplied to the Royal Australian Navy for similar duties.

Some Factors Influencing the Design of Modern Rolling Mill Drives

By H. S. BROWN, B.Eng., A.M.I.E.E., Deputy Chief Engineer, Metal Industries Division of The English Electric Company, and J. C. EASTON, A.R.T.C., Electrical Engineering Department of Colvilles Limited.

This article is in all essentials a reproduction of the paper read by the Authors at a meeting of the West of Scotland Iron and Steel Institute in Glasgow on the 17th of February 1956.

ELECTRICAL ENERGY MUST be placed high on any list of the necessities of life for the steel industry. A modern steelworks would be unable to function as it does without the electrical equipment which operates so many of its units. This equipment is continually growing in its extent and variety ; its cost as a percentage of the total cost of a new works or mill continues to increase ; the space demanded for it is increasing in many cases ; and it is becoming more intricate and complex.

In the face of these ever-increasing claims by the electrical equipment, many users, whilst recognising the necessity for much of it, question whether all that is done in the name of advancement is really necessary. Very often it is suggested to the electrical engineer that possibly he may be making a mountain out of a molehill—admittedly a large molehill.

Part I of this article endeavours to show in basic form the reasons for some of the increases that have taken and are taking place in the extent and complexity of electrical equipments for mill drives. The obvious aspects such as increase in size due to greater power requirements are not considered, as there can be little argument on such points. In Part II examples of modern mills are given which also illustrate some of the modern trends in mill drives.

Fig. 1.—*Slabbing-mill pulpit*, 1925

I. FACTORS INVOLVED

The increase in complexity, using the term in a wide sense, of the electrical equipment can be due to one or more of a number of factors. These fall into five main categories, namely :—

General rise in standards.
Capital costs.
Running costs.
Improved mill operation.
New achievements.

Each of these aspects will be considered separately.

Fig. 2.—*Slabbing-mill pulpit*, 1953

General Rise in Standards

In the majority of cases a reason for an increase in the amount of electrical equipment can be found in concrete economic factors. There is, however, the general rise in standards which electrical equipment follows in common with the rest of engineering. Standards of safety, of protection, of cleanliness, and of appearance, have risen appreciably over the past years, frequently leading to more electrical equipment. A typical example in the field of mill electrical equipment is given by comparing Figs. 1 and 2. Fig. 1 shows a slabbing mill pulpit in 1925. Fig. 2 shows the pulpit of the mill which replaced the previous mill in 1953.

Capital Costs

It may be surprising that capital costs should be included as a reason for the increased extent and complexity of the electrical equipment. The explanation is, however, that by using special control schemes or new devices the cost of certain units can often be reduced.

As an example, the size of a synchronous motor for a main mill drive, and hence its cost, is usually determined by the maximum peak power it is required to develop. The resulting frame size may be considerably larger than is required by any of the other considerations affecting it. By introducing special control features, a synchronous motor field can be rapidly forced when peak loads are applied, thus enabling it to take much higher peak loads than it could do otherwise, so that the size of motor for a given drive may be reduced considerably. For the range of powers normally met in main mill drives, the saving in cost in the motor more than pays for the magnetic amplifiers or control exciters required for the scheme.

Running Costs

The major item in the running costs of an electrical equipment for a mill drive is the energy supplied to it, and it is intended here to deal with this aspect alone. For mill drives, apart from the cost of units under the terms of any agreement with the electricity supply authority, three factors affect the energy costs per ton of steel rolled. These are :—

1. The on-load losses.
2. The light-load losses.
3. The maximum energy demand over half-an-hour that the drive makes upon the supply system.

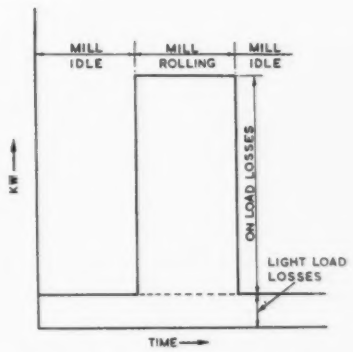


Fig. 3.—*Method of viewing losses for approximate consumption estimates*

The losses referred to are those which occur in the electrical equipment between the incoming supply to the mill area and the motor shaft. The

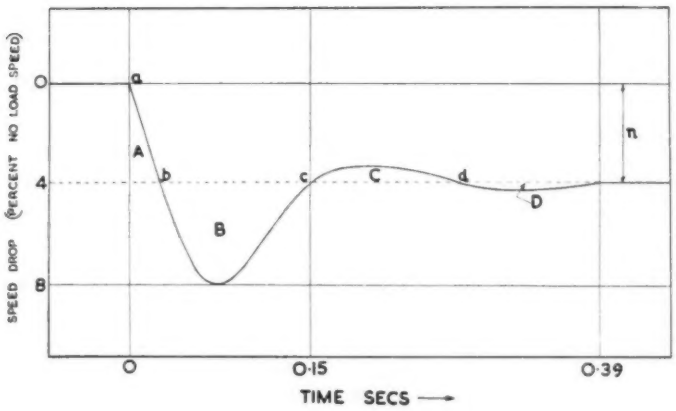


Fig. 4.—Behaviour of D.C. motor under impact load

term 'on-load losses' covers those losses which occur due to the equipment performing its duty, e.g., a main mill drive when rolling or a roller table drive when the rollers are moving. The 'light-load losses' are those losses which are constant whether or not the equipment is performing its duty, e.g., the bearing and windage losses of a motor-generator set, the losses of ventilation equipment, etc. It is convenient to consider the light-load losses as being present all the time, and the on-load losses as occurring only when the drive is performing its duty, as shown in Fig. 3.

For a continuously running drive, such as that for a 3-high mill, the on-load losses are, of course, a function only of the efficiency of the electrical equipment involved, so that the only means of decreasing these losses in such cases is by increasing the efficiency of the drive. The efficiency of the majority of large electrical machines is between 90 and 97% according to the drive, and very little change has occurred in these values in the last 40 years. However, where D.C. motors are required for the drive, the use of rectifiers instead of motor-generator sets does, in most cases, enable the overall efficiency of the electrical equipment to be increased. This is one of the reasons for the increased use of rectifiers.

Not so obvious are the losses due to the method used to control the drive in performing its duty. These losses can amount to a far greater value than the straight efficiency losses just referred to, and the possibility of reducing them frequently provides a major argument for the adoption of additional equipment. This problem can be illustrated by considering the example of the main tables of a high-output steel slabbing mill when driven by D.C. motors with (*a*) reversing plugging control, and (*b*) motor-generator set or Ward-Leonard control.

Plugging is the reversal of the supply to the motor terminals when the motor is running at full speed. During the reversal time, resistance is inserted in series with the motor armature to prevent it being overloaded. At every reversal of the motor under these conditions, energy equal to approximately four times the total kinetic energy of the mechanical system has to be dissipated in the motor armature circuit. When the number of reversals per hour is large, a great deal of energy is lost in the armature circuit resistances.

With the Ward-Leonard system the energy is not dissipated in useless heat but is returned to the system with a loss dependent on the efficiency of the motor and the generator from which it draws its power. As previously stated, the efficiencies of electrical machines are between 90% and 97%, so the resultant loss in this case is relatively small.

The examples given later show how the factors now being considered have affected the design of some equipments now in operation. Nevertheless, it is worthwhile at this point to consider one of these examples to illustrate more clearly how the losses due to the method of control can affect the economics of a drive. The ingoing and outgoing tables of a typical modern steel slabbing mill are each powered by two 150 h.p. 460 r.p.m. motors. The inertia of the tables referred to the motor shaft, for each of the motors, is 2,100 lb-ft^2 (including motor armature). For a top speed of 460 r.p.m., this gives a kinetic energy of 138 h.p.-seconds or 0·0286 kWh. The energy loss per reversal per motor is therefore 0·114 kWh. On a high-output mill of this type there may be as many as 600 reversals per hour, and since there are four motors in

all, the total energy loss in one hour by the plugging method is 275 kWh. If these roller tables had been driven from a motor-generator set with an overall efficiency of 82·5%, the energy loss per motor per reversal would have been around 0·01 kWh. For 600 reversals per hour, this gives an energy loss per hour of 24 kWh for the four sections. The proportion of the motor-generator set's light load losses to cover these drives is 60 kW, giving a total loss with the motor-generator set alternative of 84 kWh. From this point of view the use of Ward-Leonard control results in a saving of 191 kWh in one hour's rolling. The output of this mill at 600 reversals per hour would be around 300 tons per hour, so the net saving is equivalent to 0·67d per ton.

The light-load losses of a drive are present throughout the time the mill is in operation, whether or not it is rolling. Whilst on a high-output mill the value of these losses may not be of great importance, they do have an appreciable effect on low-output mills. The effect of light-load losses can again best be illustrated by a particular example.

Consider a hypothetical reversing billet mill having, say, a 1,250 h.p. D.C. driving motor. The motor might be supplied from either a 1,000 kW 600 volt rectifier equipment or a 1,000 kW motor-generator set. The motor-generator set might comprise a 1,000 kW 600 volt D.C. generator and a 1,500 h.p. 6·6 kV synchronous motor running at 1,000 r.p.m. Typical comparative data for these two schemes would be as in Table I :—

TABLE I

	Rectifier	M.G. Set	Mill Motor
Full load efficiency (including light-load losses) ..	93%	89%	93%
Light-load losses ..	14 kW	69 kW	—
Full load efficiency (excluding light-load losses ..	94%	95%	—

Consider the mill rolling from a 4 in × 4 in bloom of 1·7 tons to, say, 2½ in × 2½ in billets. A work curve based on test results shows the total work per ton for this elongation to be 49,600 h.p.-seconds ; this is equivalent to a motor output of 10·3 kWh per ton. The total kWh per ton (allowing for efficiencies and including light load losses) for several programmes of this mill are shown in Table II :—

TABLE II

Programme, tons per hour	40	30	20	10
kWh per ton—Rectifier ..	12·15	12·27	12·5	13·2
kWh per ton—M.G. set..	13·43	14·0	15·15	18·6
kWh per ton saved by use of rectifier	1·28	1·73	2·65	5·4

The increase in kWh per ton with falling output is due solely to the light-load losses. Their effect at low outputs is therefore made clear by the above figures.

Low light-load losses are another of the reasons for the increased use of rectifiers. A reversing mill was taken for the foregoing example as it is the best case for illustrating the effect of light-load losses. For other reasons, however, rectifiers have not been very widely used for reversing mills although their application in this field is increasing.

To supply the electrical energy the supply authority, of course, carries not only the cost of the actual production of this energy but also the capital cost of the equipment producing and transmitting it. The size of this equipment is usually determined by the *maximum* rate and not the *average* rate at which the energy has to be supplied. To reflect this condition the charge for electrical energy is usually made in two parts : firstly, a charge per unit of energy supplied and, secondly, a maximum-demand charge based on the maximum average kVA load over a pre-determined period—usually half an hour. When investigating energy costs it is necessary to consider the effect of both these charges, as the factors in the electrical equipment affecting the costs are not necessarily the same for each charge.

In order to keep the kVA maximum demand charge at a minimum, it is necessary to keep the power factor of the load on the electrical supply as high as possible. Recent tariff changes in many areas have increased the effect of the maximum-demand charge. Consequently it has become economical in these areas to install additional equipment to improve the power factor. This equipment usually takes the form of static condensers, with their associated switchgear, although synchronous condensers may also be used.

Fig. 5.—Slabbing-mill motor room, 1925

Improved Mill Operation

By careful design, the electrical equipment can give improved mill operation in a number of ways with consequent improvements in output, costs and quality of the product. It can give increased comfort to the operator and make his job easier ; provide automatic features and so simplify the operator's duties, and in suitable cases reduce the number of operators ; protect itself against misuse and thus allow the operator to concentrate more fully ; enable the operator to work more effectively, by responding more accurately and rapidly to his instructions ; give improved performance characteristics to the mill, and in consequence improve the quality and/or output.

The easier an operator's job is made, the more effectively he performs it. Improvements in the design of controllers, and of control systems to enable lighter controllers to be used, reduce the physical work involved. Also, by making the controllers more compact, a neater layout of the equipment is possible, thus allowing the operator to adopt a more comfortable position. This is reflected in present-day control pulpit design, where the layouts are arranged whenever possible to permit the operator to control the mill from a sitting position.

By making it easier to perform each function, the more functions is one man able to perform. The use of automatic control enables many of the operator's functions to be simplified or even eliminated. In some low-output blooming mills, the use of automatic control of the screwdown has enabled the mill to be operated by one man. In the operation of the pouring reels of high-output rod and bar mills, automatic sequencing control is a necessity if the reels are not to hold up output.

The nearer a drive can be worked to its maximum safe performance, the more is obtained from it. In some cases a skilled operator can do this very effectively, but these cases are rare. Further, the job of the operator is to process steel, and it should not be necessary for him to have to consider the possible consequences of his actions on the electrical equipment ; in steelworks installed in undeveloped areas where operators are not fully trained, this is an absolute essential.

The most common fault to be guarded against is the tendency for the operator to attempt to change the speed of the mill too quickly, thus overloading the drive and causing it to trip out. By suitable design of the control scheme, the equipment can be given inherent protection against such mal-operation. Similar protection can be provided for the mill auxiliaries. For example, hot saw feed drives are usually manually controlled, and it is possible for the operator to feed-in the saw too quickly with consequent stalling and possible damage to the saw. By the introduction of suitable controls,

the rate of feed can be limited automatically to a safe value.

The earlier methods used to protect the equipment from mal-operation by the driver almost invariably prevented the drive being worked to its maximum in many respects. For example, Fig. 11 shows the main drive controller for the 1925 slabbing mill drive which is referred to in more detail later. The driver of this mill operated the main controller from the pulpit shown in Fig. 1 through an oil servo-unit which limited the speed of movement of the controller to a pre-determined maximum value. This was very effective in protecting the motor from misuse, but it had the disadvantage that the rate of movement had to be adjusted to meet the worst conditions and was unnecessarily slow over much of the speed range. Improvements in oil servo-motors enabled the rate of response to be varied according to the position of the controller. Even so, the method introduced limitations which were unacceptable in modern high-output mills. With the advent of quick-response control exciters and magnetic amplifiers, it has been possible to design the control scheme to give the fastest response permissible at almost every part of the speed range.

The use of modern control units, such as the magnetic amplifier and quick-response control exciter, enables important improvements to be made in the performance of mill main and auxiliary drives. In blooming and slabbing mills the rates of reversal for the main drive have been reduced to between $\frac{3}{4}$ sec and 1 sec. The rates of acceleration and deceleration of the screwdowns, manipulators and other auxiliaries have been greatly improved. Not only do these greater rates of acceleration of auxiliaries give faster times of displacement but, more important, they enable the operator to make the required adjustment more accurately with less need for second chances, and thus effect important savings in time.

In cold mills, improvements in the electrical equipment have enabled the tension to be controlled more accurately and the quality of product to be greatly improved, but this aspect is dealt with in the next section.

New Achievements

In many cases the advancement of rolling techniques and mill design has had to be matched by improvements in the operation of the electrical equipment in order that the results aimed at could be achieved. It is usually these requirements which necessitate the more mystifying items of electrical equipment that are seen in the modern

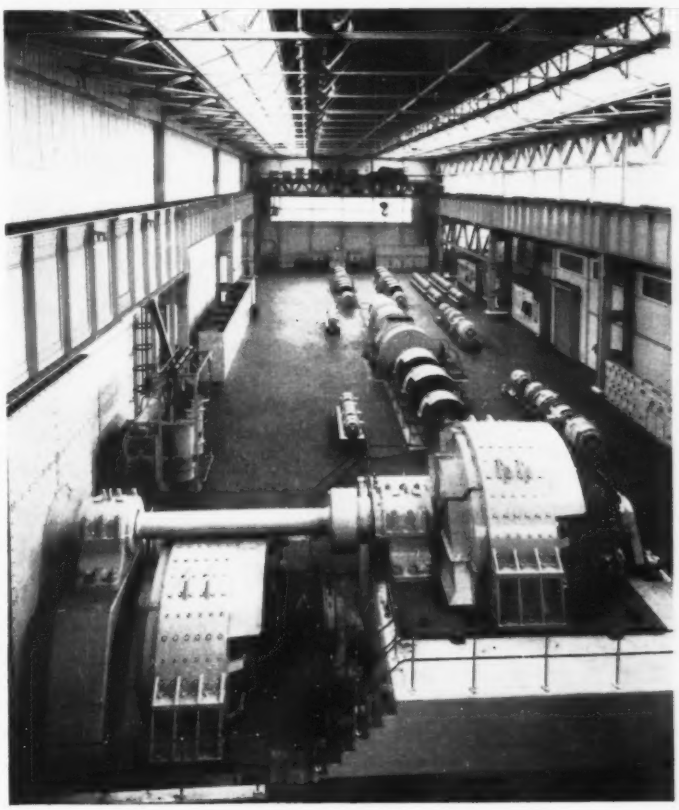


Fig. 6.—Slabbing-mill motor room, 1953

steel industry. The effect of this on the electrical equipment can only be illustrated by considering particular examples. There are many such examples both in Great Britain and abroad, but only three will be considered here, namely, the continuous hot mill main drives, flying shears and the cold mill main drives.

Continuous Hot Mill

In modern high-output rod mills, a combination of two factors frequently requires a considerable improvement in the operation of the main drives ; firstly, the desire for increased flexibility in the operation of the mill and, secondly, a demand for greater accuracy of product. The requirement of increased flexibility necessitates splitting the drive to allow the speeds of each stand or each pair of stands to be adjusted separately. This, however, immediately introduces a change in the rolling conditions, which in many instances can be detrimental to the quality of the product unless special compensating features are included in the control of the drive.

Where a number of stands are driven through a gearbox, their speeds are rigidly tied together. Thus at all times the speed of the piece matches the speed of the rolls on each stand, whether it be entering, running through or leaving the stand. When an individual electric drive is used, however, there is a variation in speed as the piece enters and leaves the rolls. This condition is shown in Fig. 4 for a stand driven individually by a motor without any special design or control features. The full curve shows the speed of the stand being considered, assuming full load is applied at time 0. It will be seen that the variation in speed comprises two components ; a constant drop in speed and a transient oscillation in speed which occurs at the application of the load. The dotted curve shows the speed of the previous stand, which is assumed for the present purpose to remain constant. Between points *a* and *b* the rolls are running faster than the piece is being delivered from the previous stand. Therefore, the area A represents stretch in the piece, assuming no slip. Between *b* and *c* the rolls are running slower than the piece, so that area B represents the formation of a loop. Area C is a partial removal of the loop. When the piece leaves the rolls the inverse happens. This latter behaviour is, of course, of no consequence in single-strand rolling but for multi-strand rolling it is just as important as the behaviour on entry.

The limitations which must be set upon these changes in speed vary greatly with the type of mill. For many hot strip mills and the roughing trains of many rod and bar mills a normal motor without any special design features or control is satisfactory. In other cases the limitations may preclude the use of a normal motor but be well within the capabilities of a specially designed motor without the necessity for special control. However, motors with a low value of speed variation with load, i.e. low regulation motors, are large for their power rating and there is an economic limit to their use. With the improvements in response and reliability of control systems that have taken place in recent years, the advantage of motors having low inherent regulation has decreased. Where it is impossible or uneconomic to meet the required performance inherently within the design of the motor, there are three basic methods of speed-holding control that can be used. In ascending order of their rates of response, these are :—

A system acting upon the motor field, the motor armature being fed from a D.C. busbar in common with other motors on the mill.

A system acting through a booster connected in series with the armature of the motor and between the D.C. busbar and the motor.

A system in which the motor is fed from its own rectifier unit and in which the speed-holding control varies the rectifier voltage through the action of the rectifier control grids.

The system adopted in any particular case depends upon the performance necessary to meet the mill operating requirements and the relative costs for the rating concerned. The additional cost of these features as a percentage of the total cost of the electrical equipment is usually not very great. It is impossible to give any figures as the cost varies greatly with the particular equipment involved. The main concern of the user is normally the additional complication that such schemes, necessary to meet his own requirements, introduce. For this reason the schemes are kept as simple and made as reliable as possible. Magnetic amplifiers

are used in preference to electronics, but if electronic equipment has to be used it is designed for steelworks service and arranged for easy maintenance and checking.

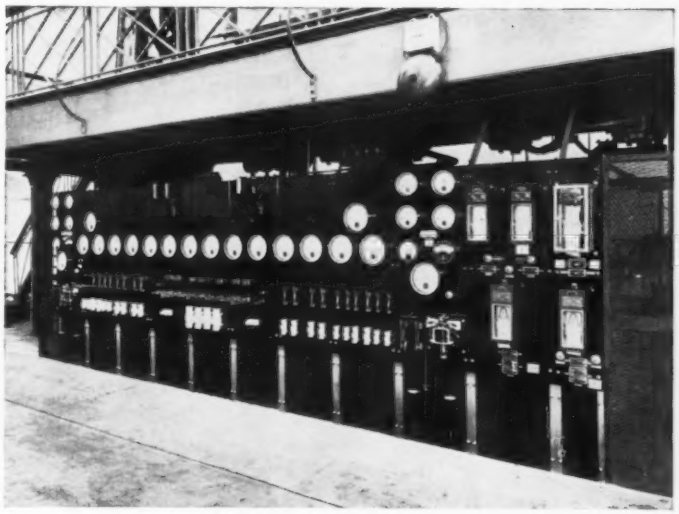


Fig. 7.—Slabbing-mill control board, 1925

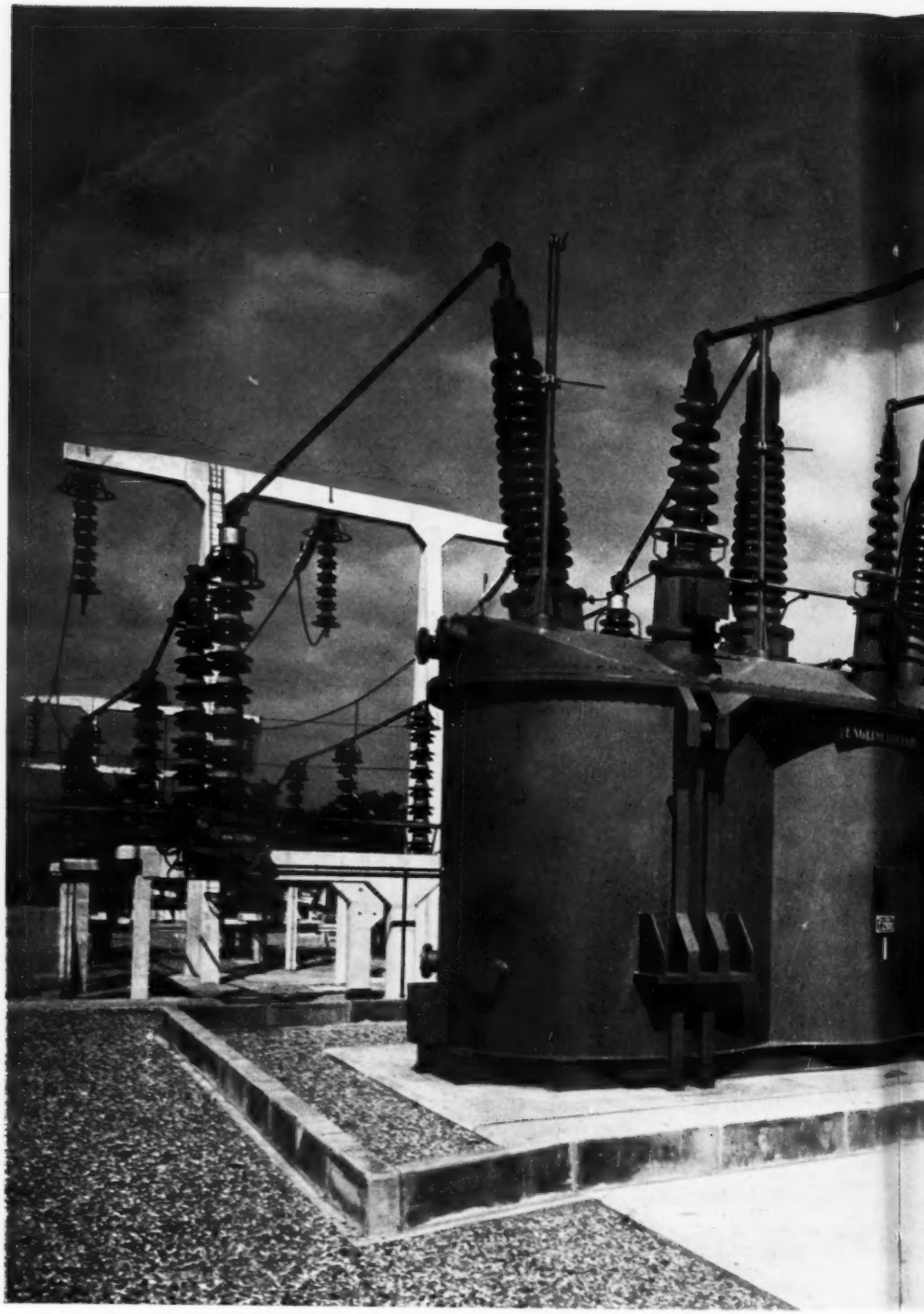
Flying Shears

Flying shears inevitably present several problems whose solution requires special features in the electrical equipment, without which the shear would not work. The control of some shears must be such that bar or strip can be measured accurately at speeds up to 2,000 f.p.m. and cut to an accuracy of $\pm \frac{1}{4}$ of one per cent. The drive may have to accelerate the blades to cutting speed in as little as $\frac{1}{4}$ second, and in spite of this short time the acceleration on a shear which is cutting bars must be controlled so that the speed when cutting is at the correct value to give a clean square cut. To achieve this operation calls for very careful design of the electrical equipment. Low inertia motors are essential, and for this reason it is frequently necessary to use two or more motors where one larger one would otherwise suffice. Ward-Leonard control is inevitable, and on some high-speed bar shears it has been necessary in the past to use a considerable amount of electronic equipment. However, with improvements in magnetic amplifier design, these more robust units can now take the place of much of the electronic equipment.

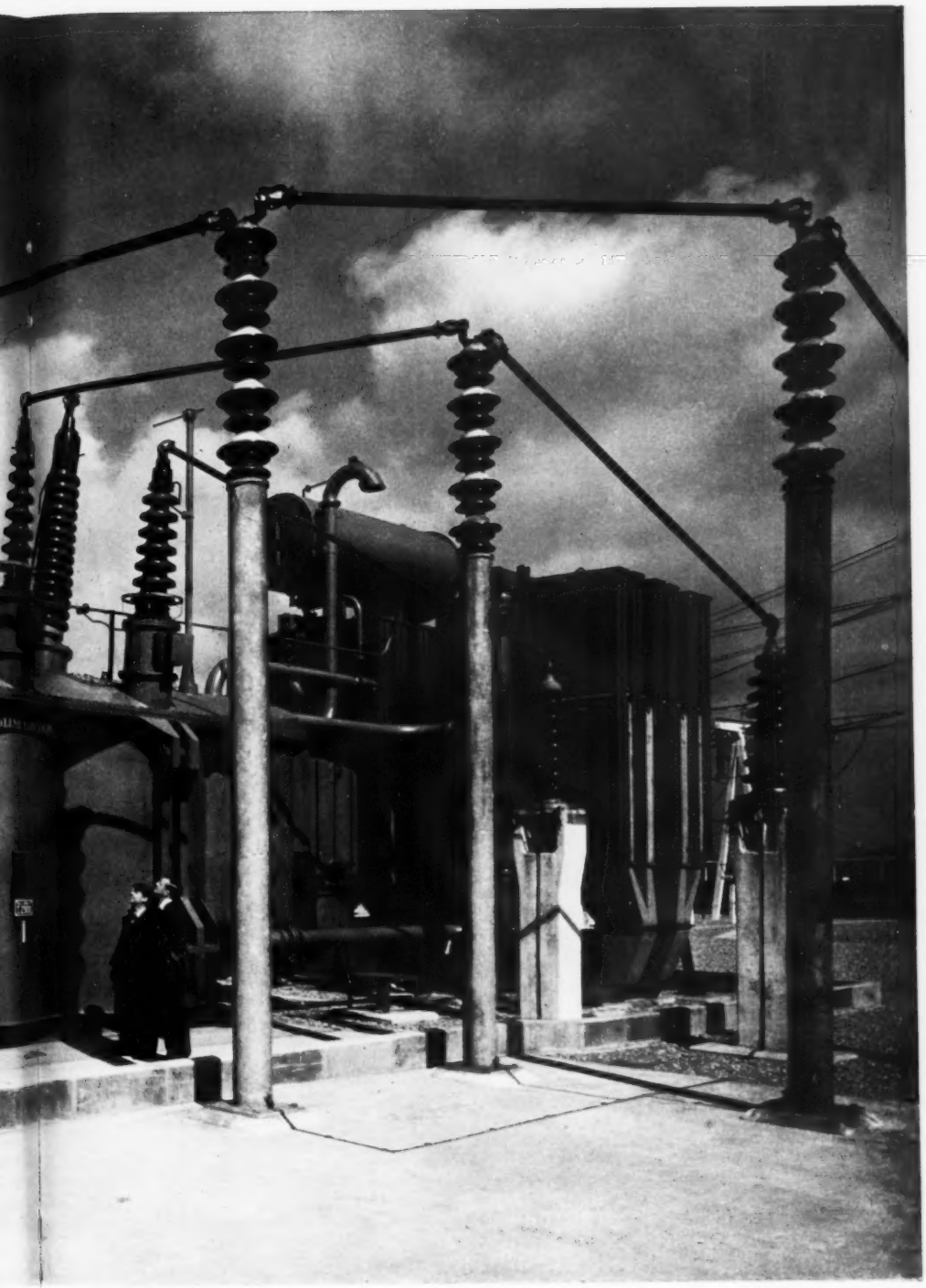
Cold Mills

Although many tandem cold mills have been in operation for a number of years it is justifiable to consider them under the heading of new achievements, as from their inception they have necessitated special control features, without which they would have been impracticable. More than any other type of mill, their growth has been inseparably linked with the developments in the electric drives. The rapid strides made in speeds and quality had to be matched by developments in control scheme design ; otherwise they would not have been possible. The important factor in the cold mill is, of course, the accuracy of gauge. This, in turn, is dependent mainly on the accuracy of gauge of the raw material and the accuracy of tension applied between stands and on the coiler. This tension must be adjustable over ranges as wide as ten to one.

When running at constant speed, maintaining constant tension is a relatively easy problem, particularly on the older low-speed mills. However, the strip must be fed into the mill at speeds as low as 3 or 4 per cent. of top speed and taken out of the mill at similar low speeds. Thus, all acceleration and deceleration takes place during rolling. If the wastage of steel due to off-gauge material is to be reduced, it is necessary to accelerate and decelerate the mill as quickly as possible and to maintain the pre-set tension as accurately as possible during these processes. A modern 5-stand tinplate mill may, for example, operate up to 5,000 f.p.m. or more, so that it is very easy to waste a considerable amount of strip during acceleration and deceleration. On these modern mills it has been possible to reduce this wastage to a low percentage by careful design of the drives and their control, but only by means of special features in the drives and the introduction of rapid response control exciters and magnetic amplifiers.



Several 120 MVA three-phase ON/OFB transformers are being supplied by The English Electri
Authority. This is one of two installed a



sh Electric Company for coupling the 275 kV and 132 kV grid systems of the Central Electricity
nstalled at the Drakelow Switching Station.

One of two 60 MVA 220 kV transformers for the Kitwe Central Switching Station of the Rhodesia Congo Border Power Corporation being off-loaded from the railway wagon on which it had travelled from Port Elizabeth, South Africa. For the last three miles to site it was taken by road. These transformers, built at the Stafford Works of The English Electric Company, are the largest yet supplied for Southern Africa.

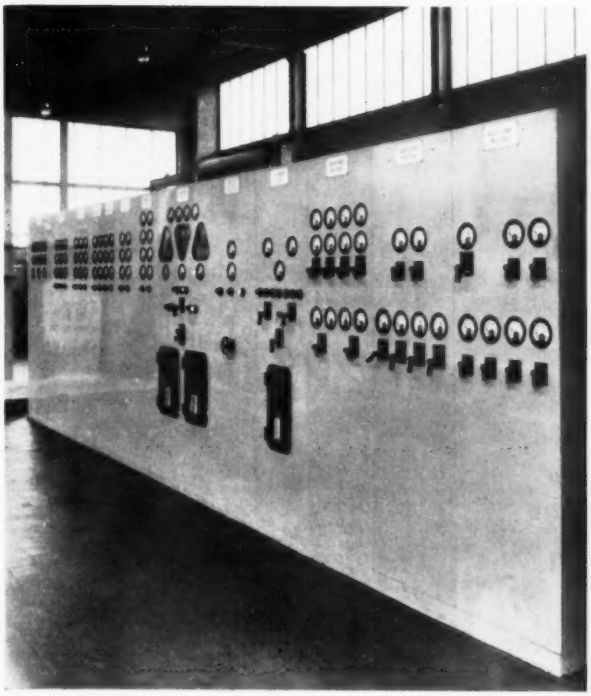


Fig. 8.—*Slabbing-mill control board*, 1953

II. EXAMPLES OF ROLLING MILL DRIVES IN OPERATION

So far an endeavour has been made to show briefly some of the reasons for the increasing amount of electrical equipment found on many rolling mill drives. In the following an illustration is given of how the factors discussed have affected the design of three typical classes of mill drive. Before doing this, however, it is appropriate to describe very briefly the three basic types of amplifier that now play such a big part in mill drive control and which have already been referred to, namely, the control exciter, the magnetic amplifier and the electronic amplifier.

Amplifiers for Controlling Mill Drives

The advances in mill drive control in recent years have been mainly the result of those made in the design of amplifiers and the circuits in which they are used. Amplifiers enable small signals to control large outputs, and enable high forcing effects to be used to overcome electrical and mechanical inertia and thus give rapid response.

In mill drive equipments three basic types of amplifier are used, each with its own particular characteristic which makes it most suitable for certain applications. The most common is the rotating amplifier or quick-response control exciter, such as the Amplidyne, Magnavolt, Metadyne, Rototrol, etc. Its big advantage over the magnetic and electronic amplifier is its lower cost and size for a given output. For this reason it is often used as a final amplifier after an electronic or magnetic amplifier.

The magnetic amplifier consists of a number of transformers, chokes, rectifiers and resistances ; its amplifying properties are obtained from the characteristics of the special material used for the cores of the chokes. Its big advantage is that it uses components which are completely static, simple and robust. It also has the advantage over the rotating amplifier that it can give a faster response. Development of the magnetic amplifier is still proceeding rapidly, and its use in the steel industry is increasing.

The electronic amplifier uses similar components to a radio set, but often these are specially made for industrial use to give additional robustness. The advantage of the electronic amplifier is, of course, the very rapid response and high amplification that it provides. It is not so robust as the magnetic or rotating amplifier, although with present-day components its reliability is of a high order. Nevertheless, in many applications its place is being taken by the magnetic amplifier.

Blooming and Slabbing Mill

Because of the simplicity of the duty that this mill performs, it might well be thought that any complication in the electrical equipment is an indication of excessive zeal on the part of the electrical engineer. The error in this can be illustrated by considering an actual example, which is of interest because it compares an old mill with the mill which replaced it. The original mill was a slabbing mill installed in 1925, and Fig. 5 shows

the motor room for this and also for a plate mill whose drive is seen in the background. The new mill was installed in 1953, and took over the slabbing duties and additional blooming duties ; Fig. 6 shows the motor room, and Figs. 1 and 2 the old and new pulpits. The considerable differences in the electrical equipment are at once apparent, and to appreciate these and why the changes have taken place, each section of the drive must be considered separately.

Main Drive

The main drive on the 1925 mill comprised a 4,600 h.p. 50-100 r.p.m. double-armature motor having a cut-out torque of 200 metre-tons. This motor was fed from two generators driven by a 2,500 h.p. induction motor with a flywheel, and the equipment was completed by a four-unit exciter set and the control board shown in Fig. 7. The drive for the 1953 mill comprises two motors, one driving each roll, with a combined output of 8,160 h.p. at 50-120 r.p.m. and a combined cut-out torque at 350 m.t. It is supplied from four generators driven by a 5,500 h.p. motor and a 200,000 h.p.-sec flywheel. Two exciter sets are provided and there are two control boards, one of which is seen in Fig. 8.

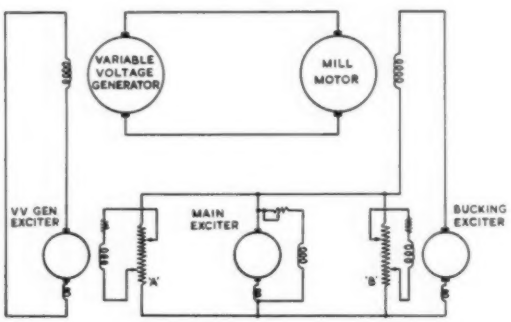


Fig. 9.—*Slabbing-mill control scheme*, 1925

Main Drive Control

Speed control of a reversing mill is effected in two stages : first armature voltage control at full motor field up to base speed, then motor field weakening at full armature voltage up to top speed. This type of speed control is adopted for most reversing mills as it best meets the rolling duty, which usually requires a high torque at low speed for certain passes and low torque at high speed for other passes.

The type of control scheme used 30 years ago is shown in Fig. 9. Speed control was initiated by movement of an oil-servo-operated controller which acted to apply a voltage from the potentiometers A and B to the exciter fields. The outputs of the exciters, fed to the fields they controlled, produced in the one instance variation of main generator voltage, and in the other variation of motor field strength. Up to 50 r.p.m. (for the 1925 mill being considered) control was obtained by raising the generator armature voltage through the action of its exciter. The motor speed was raised to 100 r.p.m. by raising the voltage of the bucking

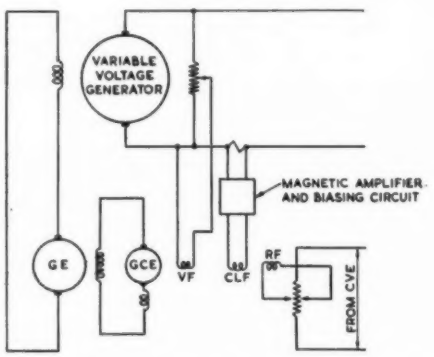


Fig. 10(*a*).—*Slabbing-mill generator voltage control*, 1953

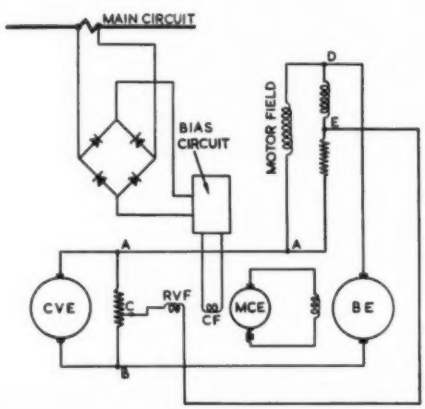


Fig. 10(*b*).—*Slabbing-mill motor field control*, 1953

exciter in opposition to the constant voltage exciter to produce motor field weakening. To overcome the inertia of the generator and motor fields, a high forcing voltage was applied in the initial stages of any change. This extra voltage was obtained from the exciters by providing excess excitation from the exciter shunt winding which was cancelled under 'normal' conditions by the action of a negative series winding.

Whilst this scheme was simple and reasonably fast, it would not meet the response requirements of a modern slabbing mill. To deal with the demand for faster reversal times combined with full inherent protection against mal-operation, additional features have been introduced into the electrical equipment of modern mills.

The basic scheme for generator voltage control on the 1953 mill is shown in Fig. 10 (*a*). In this case two exciters are used : a generator exciter GE and a series (positively) excited control exciter GCE with special quick response and temperature compensation features. Voltage control is provided by the reference field RF which is connected to various taps on the potentiometer by the operator's master controller. The excitation of RF is opposed by the voltage and current limit feed-back fields, VF and CLF. The control system acts to vary the generator voltage until the excitation of VF just balances that of RF, only a small net excitation being necessary to maintain the required generator voltage. A very high forcing voltage is therefore obtained until the generator voltage has reached its set value. The use of the voltage feed-back field and the quick-response control exciter gives a much faster response and greater accuracy of voltage control than the old system, due to the higher amplification obtained. The current-limit field only comes into action above 2·5 times full load to cause a reduction in generator voltage. At 3 times full load—the cut-out setting of the drive—the excitation of CLF is equal and opposite to that of RF, thereby reducing the generator voltage to zero.

A simplified diagram of the scheme for motor field control is shown in Fig. 10 (*b*). The bucking exciter in this case is controlled by MCE, a quick-response control exciter similar to GCE in Fig. 10 (*a*). The field RVF on MCE combines the functions of RF and VF on GCE. One end of RVF is connected to various taps on the potentiometer AB by the master controller, the other end being connected to point E in the circuit AD. AD is a low-current circuit in parallel with the motor field, having the same time constant as that of the motor field circuit, so that the voltage across AE is proportional to the motor field current under all conditions. The action of the control varies the motor field current to make the voltage across AE equal that across AC, and reduces the excitation of RVF to zero. The action of the field CF is similar to that of CLF in the generator control, only it produces positive motor compounding in place of generator voltage droop. This compounding field only comes into action above 1·5 times to twice full load. The rectifier circuit is necessary in this case to ensure that the control always acts to strengthen the field irrespective of the direction of current in the main armature circuit.

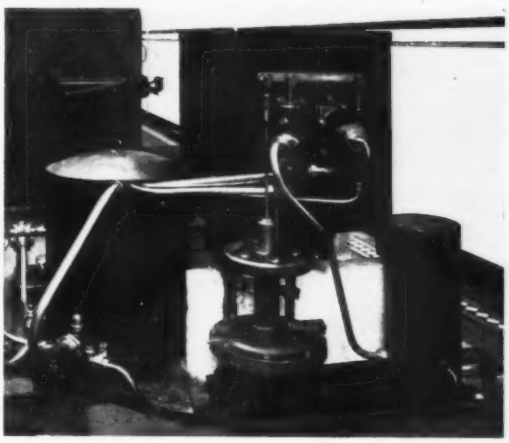


Fig. 11.—*Slabbing-mill controller*, 1925

For a twin drive, the control scheme has to be extended to embrace the two motors. Two additional features are provided :—

(*a*) Differential speed control, affecting the relative speeds of the motors when the mill is empty.

(*b*) Differential torque control, affecting the relative torques when the metal is between the rolls and the motors are thus tied together mechanically.

General Comparison of Main Drives

Considering the major items of difference between the old and new main drives :—

(*a*) Control exciters and magnetic amplifiers have been introduced, with a consequent increase in the complication of the control circuits. In return for this, however, several advantages have been gained.

The oil servo-motor and the large controller seen in Fig. 11 have been replaced by a much smaller and lighter foot-operated controller under the operator's chair.

Much faster reversal times are attainable on the new mill. Whereas on the old equipment base speed to base speed reversal times were of the order of $2\frac{1}{2}$-3 seconds, on the new drive times of $1\frac{1}{4}$ seconds are obtained. (On more recent equipments faster times can be provided, if required). The rates of response over the field-weakened range show an even greater improvement.

The new drive is self-protecting in spite of the fast rates of response, automatically reducing the generator voltage and increasing the motor field if overloads tend to be too great.

(*b*) The new drive is a twin-motor arrangement in which a separate motor is used to drive each roll. This arrangement was first tried out in 1922 with a view to using it on the 1925 mill being considered. At that time, however, it was thought wiser to adhere to the conventional arrangement using a pinion housing. Since then, considerable experience has been obtained in the use of twin drives on reversing blooming and slabbing mills and on plate mills. The twin-drive arrangement offers several advantages :—

1. In very high-torque drives the design of a suitable pinion unit becomes a major problem which the twin drive eliminates.
2. The losses of the pinion unit are omitted, and this can be a significant saving on a high-output mill.
3. The rolls are not rigidly coupled, and hence the amount of roll wear should, in general, be less due to the reduced slip.

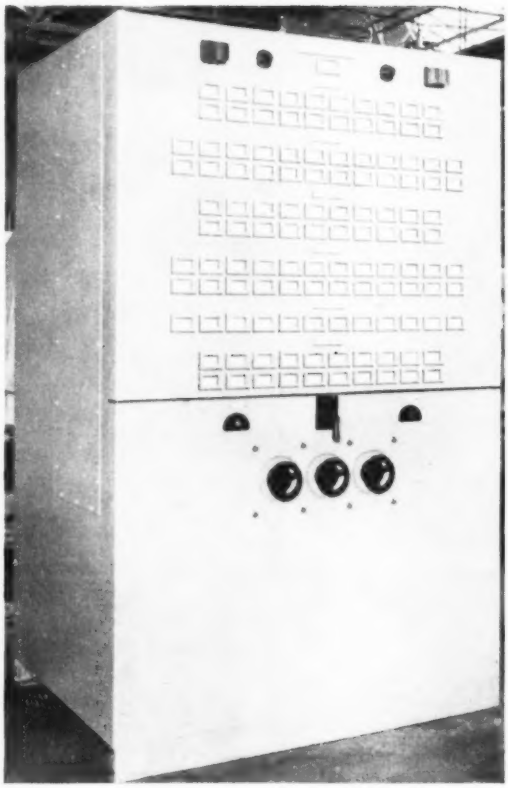


Fig. 12.—*Slabbing-mill alarms panel*, 1953

4. On the larger drives the cost of the twin drive and long spindles is usually less than that of the single motor and pinions. This is, of course, particularly so where a double armature motor would in any case be required on the pinion driven mill.
5. The twin-drive arrangement provides a lower inertia than a single armature drive, and in some cases the difference can be considerable.

(*c*) The differences in pulpit and control board arrangements are self-evident from Figs. 1, 2, 7 and 8, and indicate the effect of the general rise in standards. The control board shown in Fig. 8 is actually a centralised board from which the whole of the equipment can be started and on which the main circuit quantities are indicated.

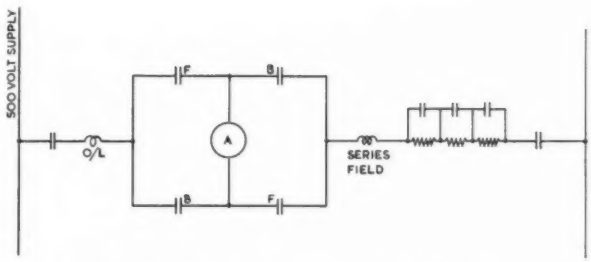


Fig. 13.—Resistance control of series motor

(*d*) In 1925 no alarm system was provided, but in 1953 a comprehensive system of alarms was installed. The alarms panel is shown in Fig. 12. Alarm systems reduce the extent to which it is necessary to depend on the skill and observation of the attendant for the continued operation of the equipment. When used with remote relaying systems and automatic shut-down features, they may even enable motor rooms to operate unattended.

As a further aid to operation and maintenance of modern control equipment, interlock test switches are provided to assist in the rapid discovery of 'open' or faulty control circuits. These, in conjunction with the alarm system, greatly speed-up the tracing of faults and reduce mill delays.

This comparison of the main drives illustrates how the performance of a mill has been considerably improved by the introduction of new electrical equipment. It might well be asked why, if the improved performance was obtained merely by the introduction of two simple exciters, was it so long in being done? The answer is, of course, that in describing the modern scheme only the basic aspects have been mentioned. The use of amplifiers in control schemes of this type is intimately associated with the design of the servo-mechanism in which they are used. Unless the servo-circuit is correctly designed, the system will be unstable. It has been in the design of these circuits as much as in the design of any amplifier that the advances in recent years have been made.

Mill Auxiliaries

The auxiliary drives for the two mills differ greatly, the screwdowns being typical of the difference. On the 1925 mill the screws were driven by two 60 h.p. motors supplied from the works 500 volt D.C. system and controlled by contactor resistance starters. The maximum screwing speed was 230 inches per minute. On the 1953 mill Ward-Leonard control of two 150 h.p. 460 r.p.m. motors is used, each motor being supplied from its own generator. The design of the equipment is such that the motors can be run at up to twice their normal voltage to give 300 h.p. at 920 r.p.m. This gives a screwing speed of approximately 400 inches per minute for high lifting on edging passes.

Auxiliaries Control

Fig. 13 shows the basic principles of simple reversing plugging control similar to that used on the 1925 mill. The operator's controller initiates the appropriate sequence of opening and closing of the various contactors to give the required direction of rotation and approximate speed. The operation of the contactors is automatically controlled, so that the necessary amount of resistance is kept in circuit for the time required to prevent overloading of the motor.

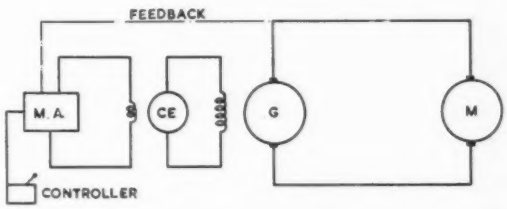


Fig. 14.—Simplified diagram of Ward-Leonard control

Fig. 14 shows the Ward-Leonard scheme of the 1953 mill. The motor speed is controlled by varying the output voltage of the generator G. This, in turn, is controlled by varying the generator field by the action of the exciter CE and the magnetic amplifier MA. The operator's controller acts directly in the magnetic amplifier circuit, and the drive is made self-protecting by feed-backs from the armature circuit to the magnetic amplifier.

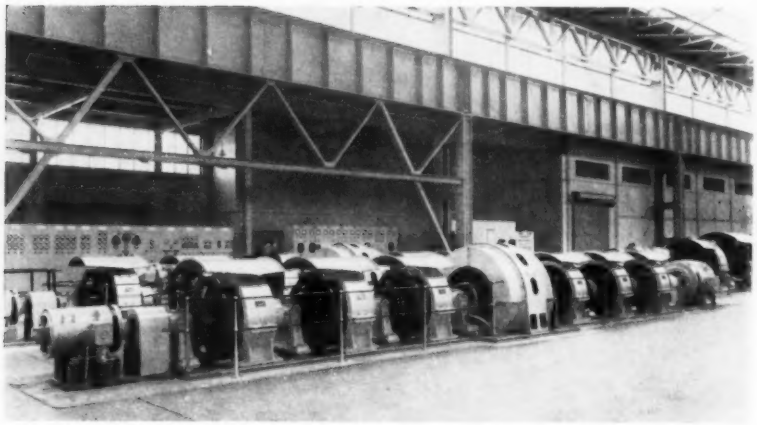


Fig. 15. — *Slabbing-mill Ward-Leonard auxiliaries, motor-generator sets*, 1953

General Comparison of Auxiliaries

The main difference in the auxiliaries of the two mills under consideration lies in the introduction of the Ward-Leonard system of control. A considerable amount of additional equipment has been introduced. In particular, there are the two motor-generator sets shown in Fig. 15 together with their associated control exciter sets and magnetic amplifiers. If the old system of contactor control had been retained, the works D.C. system would have had to be extended. Nevertheless, there is a considerable investment involved in the changes made, but Ward-Leonard control is now almost universally adopted for the main auxiliaries on heavy reversing mills because of its many advantages, which can be considered under several headings :—

(*a*) Energy Losses. An example of how the method of control can affect these losses is given in Part I of this article, under ' Running Costs ' on page 15. The example taken is that of the main tables of the 1953 mill now being discussed. It was shown that for reversal losses a saving of 0·67d per ton could be achieved by the use of Ward-Leonard control. When the remainder of the auxiliaries are considered, such as screwdowns and manipulators, the saving can be further increased.

(*b*) Operation. The Ward-Leonard method of control gives faster acceleration and retardation. As already pointed out, this not only cuts displacement times but also gives greater accuracy of control with a further decrease in operating times.

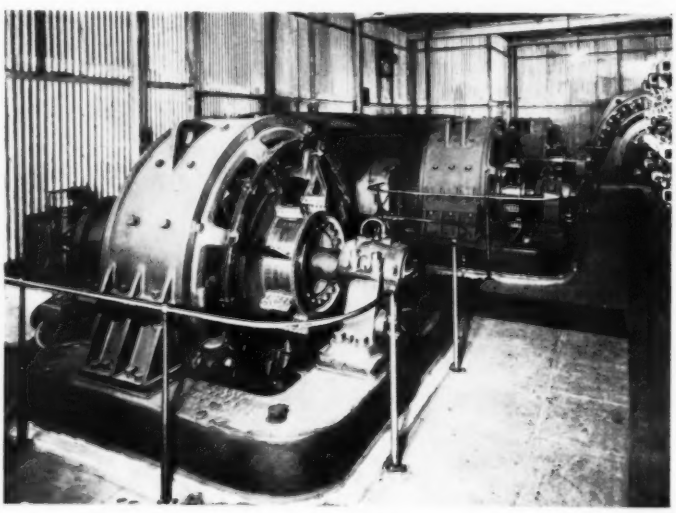


Fig. 16.—*Rod-mill motor room*, 1933

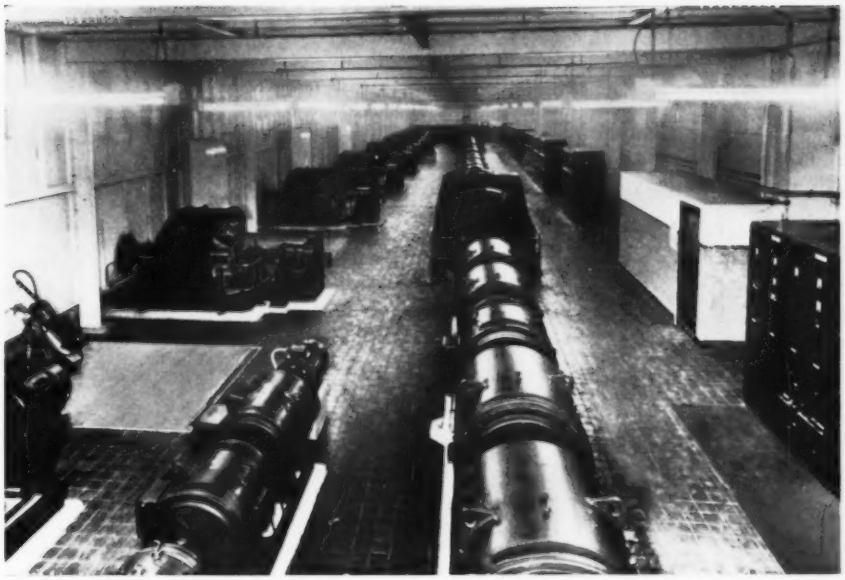


Fig. 17.—*Bar-mill motor room*, 1954

(*c*) Electrical Maintenance. The contactors used on contactor resistance starters for the powers concerned are large and, whilst modern contactors are very good, they naturally require regular maintenance when subjected to 600 operations per hour. With the Ward-Leonard system the current in the control circuits is small, and consequently the contactors are smaller and have a much easier duty. In the more recent schemes most of the frequently operated contactors and relays have been eliminated completely.

(*d*) Mechanical Maintenance. The Ward-Leonard system maintains the current at a fairly constant value, whereas contactor control gives a number of current peaks as the contactors close. For a given rate of acceleration or deceleration the build-up of current is much smoother with Ward-Leonard control. These factors ease the duty, and hence the maintenance, of the mechanical equipment in many instances since they eliminate shock loading.

The introduction of quick-response control equipment to the main drive resulted in a considerable reduction in operating times. To utilise this advantage to its fullest extent, the control of the auxiliaries had to be improved to match the operation of the main drive. The advantages of Ward-Leonard control, enumerated above, gave the required operational characteristics and led to the adoption of this system for the mill auxiliaries.

Rod and Bar Mills

The maximum contrast on this type of mill would be obtained by comparing an old looping mill with a modern continuous mill. This would not, however, fulfil the object of this article, as the continuous mill has been in use for many years and its main features are well known. Three examples of continuous mills will therefore be considered : a 4-strand rod mill installed in 1933; a single-strand bar mill installed in 1954 ; and a two-strand rod mill recently commissioned. Fig. 16 shows the motor room of the 1933 mill, and Figs. 17 and 18 show, respectively, the motor rooms for the bar mill and two-strand rod mill. Again, there are a number of differences between the electrical equipments for the three mills, which illustrate the aspects outlined in the first part of this article.

Main Drive

In the 1933 mill the stands were driven as shown in Table III :—

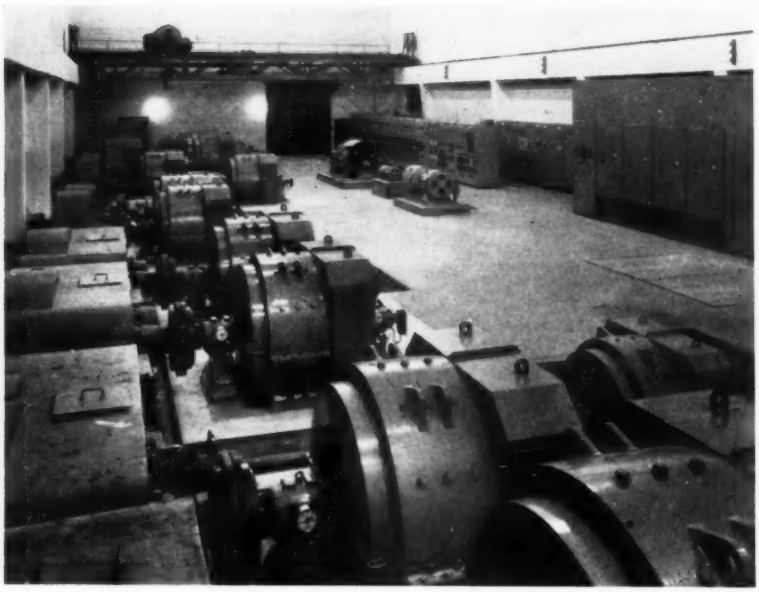


Fig. 18.—*Rod-mill motor room,* 1955

TABLE III

Stands	Motor h.p.
1 to 7	1—1,600
8 & 9	1— 750
9 & 10	1— 750
11 (looping)	1— 500
12 (looping)	1— 500
Each 6-stand finishing train	1—1,200

All motors were designed with a low inherent regulation, as control system design at that time was not sufficiently advanced to give the response desired if speed-holding control had been used in conjunction with normal motors.

In the two-strand rod mill which rolls the same product as the 1933 mill, individual drives are used for all stands except the 6-stand finishing train. A considerable increase in the flexibility of the mill is thus obtained. Low regulation motors were again used without any special control for speed holding. The two-strand mill was being installed in a new works in a situation where it was felt that there might be difficulty in obtaining maintenance men familiar with the type of control equipment necessary to give effective speed-holding control. Operational experience had shown that motors designed for low inherent regulation would meet the requirements of this type of mill. Although, therefore, a less expensive motor plus a speed-holding control system would have been cheaper, it was decided to favour the simplicity of a low inherent regulation motor.

The single-strand bar mill has individual drives on all stands in order to give the utmost flexibility in operation. To ensure the high quality of product required, it was essential that the finishing stands should not roll under tension. At the same time, at the speeds involved, excessive loops could easily

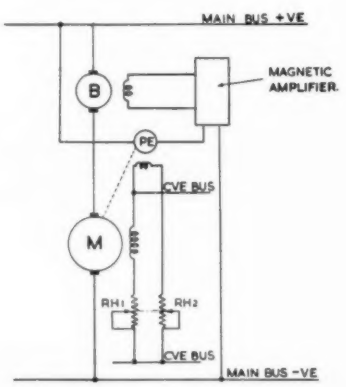


Fig. 19.—*Basic control for bar mill main drive*

develop if the stand speeds were incorrectly set. These requirements could only be met by the use of a speed-holding control using armature boosters. With this control it was possible to use normal motors, and the cost was in fact less than that for motors having low inherent regulation and no special control. The armature booster sets can be seen in the centre of the motor room (Fig. 17) in line with the main motor-generator sets.

Bar Mill—Main Drive Control

The basic principles of the control scheme for the main drive are shown in Fig. 19. The motor armature is fed from a D.C. busbar whose voltage is maintained constant at a pre-set value. The motor field is fed from a constant voltage supply through the speed regulating rheostat RH1. Connected to the motor shaft is a pilot exciter PE with its field fed from the constant voltage supply through a series rheostat RH2 ganged to the rheostat RH1. Since the pilot exciter is coupled to the motor shaft, with fixed excitation its armature voltage is proportional to the motor speed. By suitable design this voltage is made equal to the busbar voltage when the motor is running at the set speed. The pilot exciter voltage is compared with the busbar voltage and the difference used to control the magnetic amplifier. This amplifier controls the voltage of the booster B, so that any deviation of the pilot exciter voltage from the busbar voltage is corrected by a change in motor speed under the action of the booster voltage.

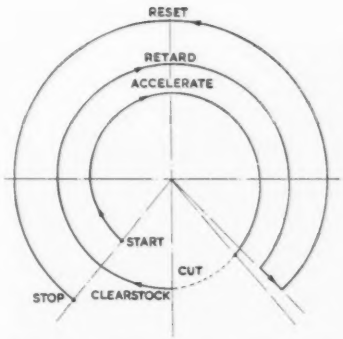


Fig. 21.—Flying shear—duty cycle

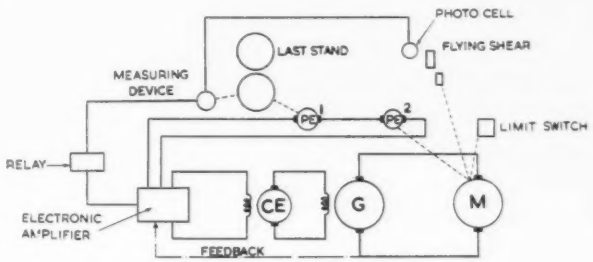


Fig. 22.—Flying shear—basic control scheme

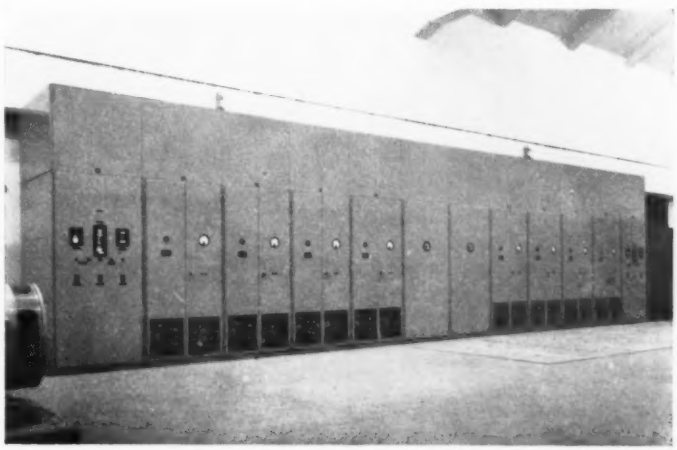


Fig. 20.—Rectifier equipment for rod-mill main drive, 1955

Main Drive Supply

In 1933, the motor-generator set was the universally accepted means of conversion for rod and bar mills. Since then, however, considerable improvements have been made in the design of rectifiers, so much so in fact that rectifiers have almost completely replaced motor-generator sets in new hot continuous mills. Rectifiers supply the drives for the two-strand rod mill, and are shown in Fig. 20. They offer several advantages: they are lower in initial equipment and

building costs ; they have a higher efficiency and lower light-load losses ; and being almost static, they require less maintenance.

Flying Shear

The speed-holding control on the bar mill main drive illustrates the need for special electrical features to meet new mill requirements. The necessity for these special features is even more clearly illustrated in the flying shear drives on this mill. There are two shears—a cropping shear before the finishing train and a dividing shear immediately after the finishing train. Since the dividing shear sets the most difficult problem, this one will be considered.

This shear must perform the following duties :—

Cut bars from $\frac{3}{8}$ to $1\frac{3}{8}$ inch in diameter travelling at any speed between 700 and 1,800 f.p.m.

Give a clean square cut. This means that the speed of the blades must be close to the bar speed ; in fact, at the instant of contact the blades run slightly faster than the bar to allow for the speed drop during the cut.

Cut lengths from 170 to 230 feet. This cut length is adjustable from the desk.

Fig. 21 shows diagrammatically the duty cycle of the shear. The nature of the problem is indicated by the speed at which this is performed. The blades must accelerate to the cutting speed at a controlled rate in as little as 0·25 second. This acceleration must be adjustable to cater for variations of bar speed. Following the cut, the blades must stop in 0·25 second and then re-set to the 'start' position. When the accuracy of $\pm 0{\cdot}25\%$ is borne in mind, it will be appreciated that the control scheme designer is set a severe problem.

Flying-Shear Control

Fig. 22 shows the basic control scheme for the bar mill flying shear. The diagram shows a single motor, although in fact two motors were used to keep the inertia low. The speed of the motors is controlled solely by variation of the generator voltage G, which is in turn controlled by the electronic amplifier via the control exciter CE. When the front end of the bar passes under the photo-cell, the light from the hot metal is detected and a signal sent to the length-measuring device driven from the last stand. This starts the measuring sequence. When the length measured reaches the pre-set value, the relay is operated and starts the cutting sequence.

The speed to which the shear is accelerated is determined by comparing in the electronic amplifier the signals from the two pilot exciters PE1 and PE2. Feed-back circuits are provided from the motor armature circuit to the electronic unit to prevent the motors being overloaded. It is not possible to show in a basic diagram the action of the various adjusting features. On the pulpit desk, however, control switches are provided to adjust for the length to be cut, the depth of bar to be cut and the roll diameter in the last stand. Bar speed is compensated for automatically.

At the time this particular shear drive was designed, electronic equipment was unavoidable.

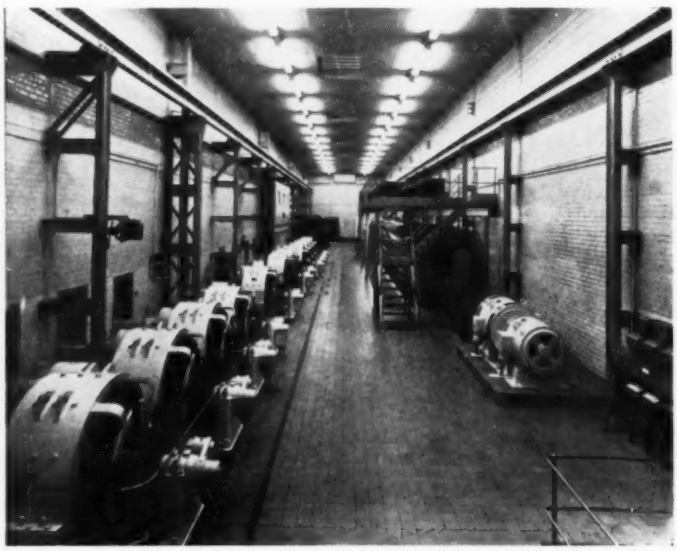


Fig. 23.—Rod-mill motor room, 1953

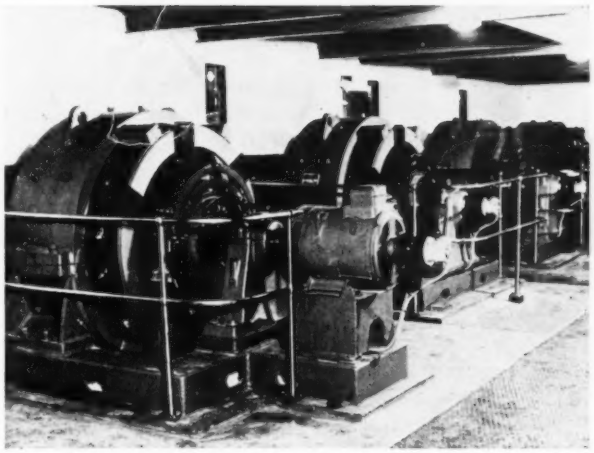


Fig. 24.—*4-stand cold-mill main drives*, 1947

The advances that have since been made in magnetic amplifier design, however, would now enable these more robust units to be used.

In these examples of hot continuous mills, the layout of the motor rooms again illustrates the general rise in standards. It is particularly interesting to compare Fig. 16 with Fig. 23 which shows the motor room of a rod mill which was installed by the same company in 1953.

Cold Mill

Considerable advances have been made in the technique of cold mill control and operation in recent years.

Fig. 24 shows the main drives for a 4-stand 14 inch wide cold mill installed in 1947 ; the four 350 h.p. motors were supplied from a single generator driven by a 1,350 h.p. synchronous motor. Fig. 25 shows the drives for a 42 inch wide 5-stand mill which was commissioned at the end of 1955 ; these are supplied from two motor-generator sets each driven by a 9,000 h.p. motor. In addition to the equipment shown in the illustration there is a considerable amount of control equipment including control exciters and magnetic amplifiers situated in the basement.

The earlier 4-stand mill had a very simple electrical arrangement. The stand motors were fed in parallel from the one generator and had no control equipment other than protective and set-up relays and a field rheostat for speed adjustment. The 90 h.p. reel motor was also fed from this generator through a booster control, and the tension was maintained constant by a single Brown-Boveri regulator acting on the motor field.

Fig. 25.—*5-stand cold-mill motor room*, 1955

The 5-stand mill is much larger and the motors are as given in Table IV.

TABLE IV

Stand	h.p.	No. of armatures
1	1,750	1
2	3,500	2
3	4,000	2
4	4,000	2
5	5,500	3
Coiler	950	2

Each armature is supplied from its own generator, and a speed-holding control using magnetic amplifiers and control exciters is provided for each stand. Coiler tension is held by magnetic amplifiers controlling both the generator voltage and motor field.

The difference in the electrical equipment for the two mills results solely from the difference in mill requirements. Whereas the 14 inch wide 4-stand mill delivers strip at the rate of 600 ft per min, the 42 inch wide 5-stand mill delivers at 5,000 ft per min, that is, nearly 8½ times as fast. The new requirements could not have been obtained on the 5-stand mill without the special control features provided.

The drive for Stand 5 is a typical example of how the electrical equipment can be affected very appreciably by the mill requirements. To keep the strip wastage due to acceleration to a minimum, the mill accelerates to full speed in 10 seconds under load. This corresponds to a rate of acceleration of the driving motor of 91 r.p.m. per second. Since the inertia of the motor is the major part of the total system inertia, it was essential to keep the motor inertia to a minimum. To do this without exceeding satisfactory design limitations necessitated the use of three armatures, as can be seen in Fig. 25.

The accuracy of tension required between stands and onto the coiler could not have been obtained without the special control features made possible by the use of magnetic and rotating amplifiers and individual generators for each motor armature.

Conclusion

An endeavour has been made in this article to show that the increasing complexity of the electrical equipment for rolling mill drives is not merely ' science for the sake of science '. In the design of modern equipment all features of the mill operation from the requirements of increased production to the comfort of the operator have to be considered.

The control equipment for a modern main drive can be considered in two sections : firstly, essential equipment in the form of control exciters and magnetic amplifiers, and secondly, additional equipment that comes under the heading of ' general rise in standards ', for example, the centralised control boards and alarm panels.

The equipment in the second category is considered by many to be an added complication and quite unnecessary for the operation of the mill. The alarm scheme and special test features of modern control equipment, however, are essential if fault conditions are to be quickly analysed and production maintained at a high level. This advantage compensates for the increase in capital cost that results from their inclusion.

The modern control schemes with their faster operating times and finer control of the process are the electrical engineer's answer to the problem of producing a better and more abundant product at a lower cost.

Acknowledgements

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They also thank their colleagues in Colvilles Ltd and The English Electric Co. Ltd for their assistance in the preparation of the article.

Modern Extension to the Port Fouad Power Station on the Suez Canal

By F. T. R. PROCTOR, Diesel Engine Division.

THE SUEZ CANAL COMPANY, founded as a result of the wisdom and foresight of a Frenchman, Ferdinand de Lesseps, has grown to be one of the most internationally important organisations in existence.

There has been a vast increase in shipping and tonnage between the opening of the canal in November, 1869, and the present time. During 1870, 486 transits were made, representing a total tonnage of 436,609 ; these figures have steadily increased and in 1955 the number of ships passing through the canal totalled 14,666, representing a tonnage of 115,756,398.

This enormous increase in traffic has called for ceaseless effort to improve and generally maintain the canal itself and to expand the attendant facilities such as dredging equipment, workshops, fresh water supplies and accommodation for personnel.

Owing to the desert conditions which prevail over much of the land through which the canal passes, housing and welfare of employees, and the provision of fresh water, have been two considerations to which continuous attention has been devoted since the task of constructing the canal began. In consequence the visitor now finds modern housing estates laid out among parks and gardens, making a pleasing contrast with the arid surroundings.

Power Generation

The demand for electric power is considerable and is expanding continuously. To meet this requirement power stations have been built at Port Fouad and Port Said, which, in addition to providing for the needs of the workshops, water filtration plant and free zones, also provide power for lighting Port Fouad and supply part of the lighting load for the town of Port Said.

The installation at Port Fouad has recently been modernised and extended by the addition of four 'English Electric' diesel alternator sets, and a fifth similar unit is to be installed this year.

The modern building, which has been described as the most up-to-date power station in the Middle East, stands approximately 65 feet above the general level of the Maritime Canal. It overlooks the harbour installations of both Port Fouad and Port Said, where ocean going vessels enter and leave the 100 mile water-way.

Generating Plant

The supply of all mechanical and electrical plant for the Port Fouad power station extension and the supervision of its erection were undertaken by The English Electric Company.

The four new prime movers installed (Fig. 1) are diesel engines from the 'English Electric' SRL series, and are mounted on separate foundation blocks. Each engine has seven cylinders of 15 inch bore and 20 inch stroke and is of the totally enclosed monobloc type having pressure lubrication of all moving parts. A type TS 400 exhaust gas driven turbo-blower of Napier manufacture is fitted to each engine.

Local ambient temperature and humidity reduce the continuous site output of each set to 1,098 b.h.p., the normal British Standard rating when operating at 375 r.p.m. being 1,312 b.h.p.

An 'English Electric' 770 kW 5,500 volt salient pole revolving field alternator is driven by each engine through a solid half-coupling, and the totally enclosed exciter is in turn flexibly coupled to the alternator shaft.

All units are capable of operation not only in parallel with one another but also with two additional generating sets which operate in the Raswa power station situated some 4 kilometres distant.

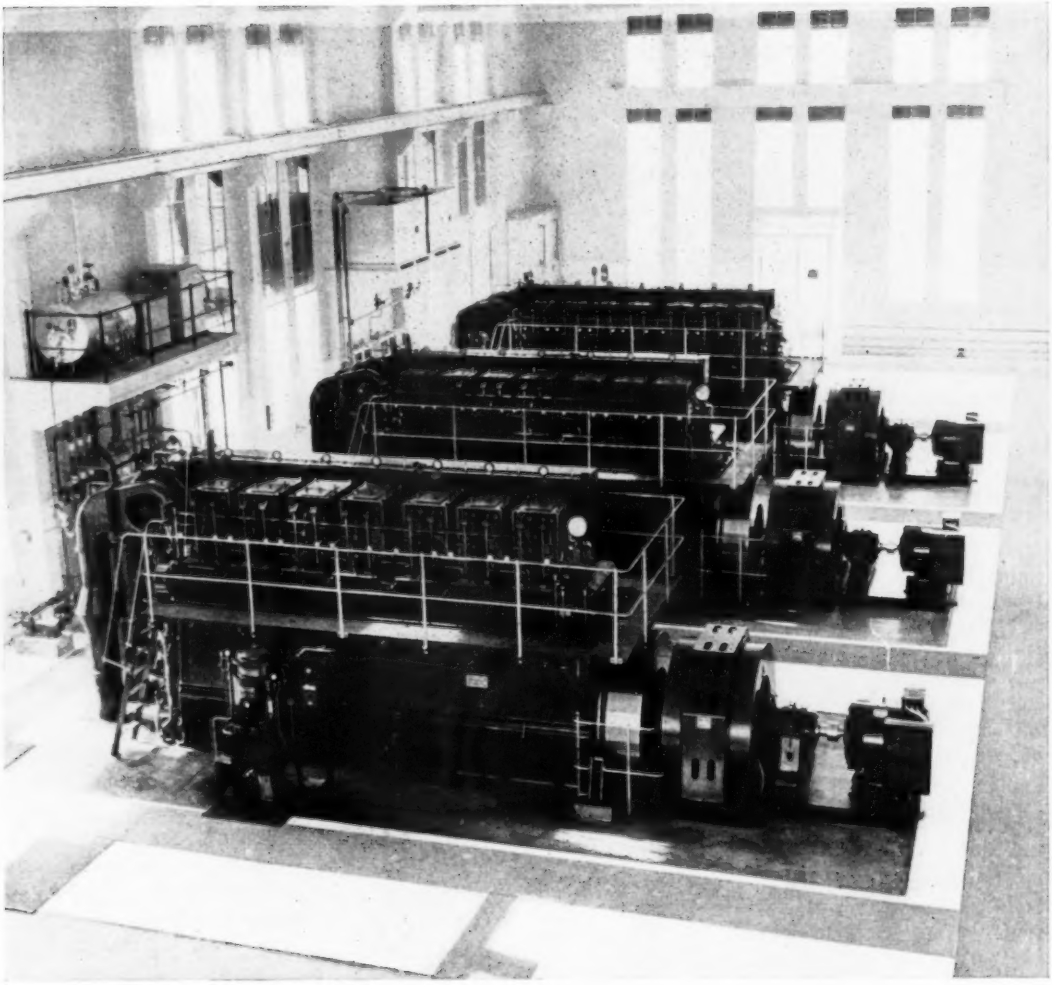

Fig. 1.—Three of the four new 1,098 b.h.p. diesel alternator sets in Port Fouad Power Station

Cooling Plant

Although ample supplies of fresh water exist for general use, the close proximity of an unlimited amount of sea water naturally influenced the type of cooling system employed. It is of the closed circuit type using heat exchangers.

The sea water is drawn from a shallow well fed from the canal, and is pumped through the heat exchangers by one of two English Electric-Worthington Simpson motor-driven monobloc pumps at the rate of 950 gallons per minute. The water then returns to an adjacent hot well from which it flows via a culvert back into the canal.

Engine driven pumps circulate fresh water through the engine jackets and heat exchangers, the circuit being topped up from a buffer and expansion tank which is mounted near the distillation plant.

Distillation Plant

One of the many services offered to users of the canal is that of a distilled water supply for ships. Previously, distillation was carried out by utilising

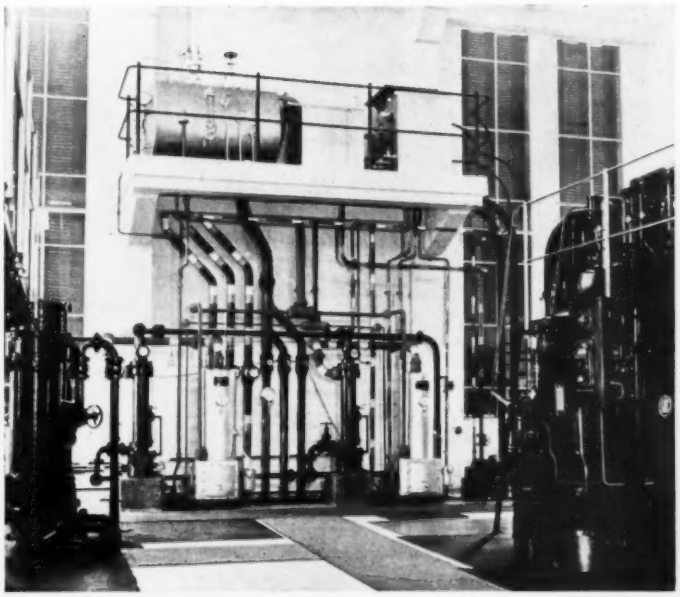

Fig. 2.—The distillation plant

steam from the old steam power station. However, with the recent change to diesel power generation an alternative source of supply was essential. By utilising heat from the engine exhaust gases in the new power station, this problem was effectively overcome, and in addition a high overall thermal efficiency is achieved.

The distillation plant (Fig. 2) consists essentially of three Type H.E.G.A.V/100 exhaust-gas boilers connected to the engine exhaust outlets, a steam and water drum, two evaporators and two distilling condensers. With the exception of the exhaust-gas boilers all the equipment is installed in the main generating room, adjacent to the free ends of the engines. All the associated pipework is clearly marked in distinguishing colour bands to denote its function.

In the first stage of the process, hot water is circulated between the exhaust-gas boilers and the steam drum where steam collects. Steam from the drum passes through the coils of the evaporators and, after circulation, returns to the drum via a mains supply feed water tank.

In the secondary circuit of the system sea water is passed over the coils of the evaporators and the resulting vapour passes to the condensers, where it is cooled by a third circuit of sea water which runs to waste. The resulting distillate is drawn off from the condensers to be stored for use as required.

Each of the two evaporators and condensers are capable of producing 150 litres of distilled water per hour when supplied with 6,000 litres per hour of sea water at 35°F.

Fig. 3.—The basement accommodating auxiliaries and pipework below the engine room

Auxiliary Equipment

As illustrated by Figs. 1 and 3, by utilising a basement type of building construction, accommodation for auxiliaries has been provided below the engine room floor level, which improves the appearance within the station. Space in the basement has been further utilised for accommodating pipework interconnecting the engines and their auxiliaries, so minimising trenches in the engine room floor.

The auxiliary equipment in the engine room consists of distillation plant, starting air receivers and lubricating oil filters. Such items as sea-water circulating pumps, fuel oil storage, heating and centrifuging equipment, and air compressors, have been arranged in the basement.

Engine lubricating oil is filtered on a continuous by-pass system by means of Streamline filters, one of which is situated adjacent to each engine. A diesel-engine driven air compressor is provided as a standby to the electric-motor driven unit of similar capacity.

The exhaust-gas boilers are also located below floor level and are so equipped that the exhaust gases can if necessary by-pass the boilers and flow to atmosphere via the silencers provided.

Dust storms are frequent during the spring months, and the danger of fine particles of sand suspended in the atmosphere penetrating the machinery had to be overcome. The air intake system of each engine therefore incorporates viscous air filters situated in the power station wall at ground level, the ducting being carried through underground channels and up through the power station floor to the turbo-blower inlet. The totally enclosed exciters are also equipped with air filters.

Fuel Storage Facilities

The location of the power station directly on the quayside facilitates the discharge in bulk of the fuel supply from the tankers to the two adjacent main storage tanks (Fig. 4) which each have a maximum capacity of 100 cubic metres. With three engines on continuous full load operation, the fuel oil contained in the tanks would ensure well over 300 hours running before replenishment.

Fig. 4.—Main fuel storage tanks

The main tanks are also required to supply ships, such as ferry boats, which draw alongside the Port Said wharf. A small motor-driven transfer pump has been installed in the compound for this purpose, as well as for transferring fuel from the main tanks to the 10 cubic metre capacity daily storage tank in the power station basement. The latter tank, in turn, acts as the base supply for individual daily service tanks mounted on the power station wall adjacent to each engine. Here again, transfer is accomplished by either one of two motor-driven pumps installed in the basement, if direct transfer is required. Alternatively, the fuel can be drawn from the daily storage tank into two heaters and centrifugal purifiers from which, after cleansing, it is delivered to the individual service tanks.

The accurate checking of fuel consumption and the individual performance of each unit is obtained

by the use of fuel meters fitted to the fuel delivery line of each engine.

Switchgear

The new switchgear installation at Port Fouad was also supplied by The English Electric Company. This comprises the 5,500 volt main oil-break switchgear controlling the supply from the generating sets and outgoing feeders, the control room equipment, and a 380 volt air-break switchboard for the station auxiliaries. The power is distributed externally by means of an underground cable network.

High-voltage Equipment

Cellular type construction has been used for the high-voltage oil circuit-breaker installation which comprises twenty-eight cells arranged in two rows back-to-back and divided into three sections by means of section isolators. The alternators are connected to the centre portion, and the feeder cells occupy the two end sections.

Each oil circuit-breaker has a normal current rating of 400 amp, a breaking capacity of 150 MVA at 6.6 kV, and is electrically operated from the control room. The mechanism is fitted with a making-current release.

Operation of each isolator is from the front of the cell, Castell-key interlocking preventing the door being opened with the isolator in the closed position.

Control Room

The balcony overlooking the main generating sets forms the control room for the station (Fig. 5). All equipment installed on this balcony is so arranged to enable the operating staff to see at a glance the conditions applying to each of the sets which may be running.

The equipment comprises a twenty-eight panel control and relay board, a five panel field suppression board, a five panel automatic voltage regulator board and a seven panel control desk. Two synchronising pedestals are provided, one on each side of the desk from which the operator controls the alternators, the Raswa feeders and a synchronous condenser. Provision has also been made for the control of future generating sets not yet installed.

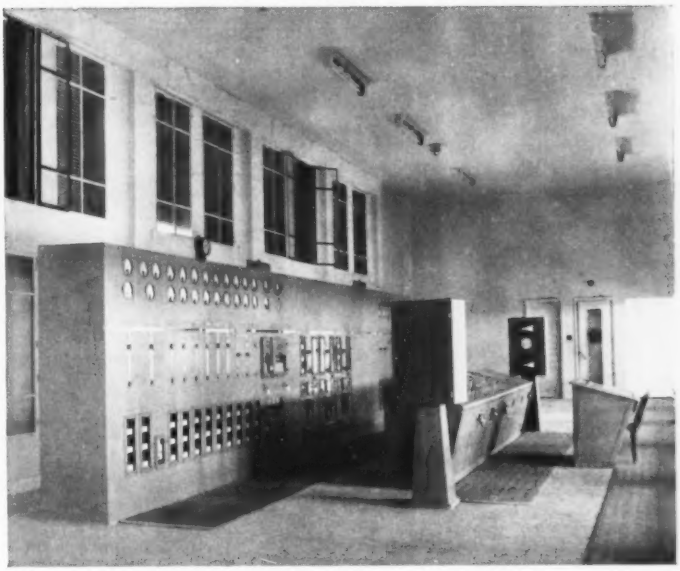

Fig. 5.—The control room

The alternators are protected by Merz-Price circulating current, reverse power, overvoltage and back-up overcurrent relays. Synchronisation of the alternators is carried out by automatic synchronising and voltage paralleling relays which ensure that the breakers cannot be closed until the speed, phase and voltage of running and incoming alternators coincide within close limits.

Low-voltage Equipment

Two 300 kVA step-down transformers reduce the voltage from 5,500 to 380 volts for the power station auxiliary supply, one being for standby duty.

The auxiliaries are controlled from a totally enclosed and vermin-proof air-break switchboard comprising two 600 amp Type OB.2 circuit-breaker

cubicles extended by sixteen 150 amp 'Combination' fuse-switch units. The OB.2 air circuit-breakers have a breaking capacity of 15 MVA at 400 volts.

The auxiliary supply for the closing, tripping and indication of the H.V. oil circuit-breakers is obtained from a nickel-cadmium alkaline battery with a capacity of 320 ampere-hours at the 10 hour rate.

Future Extensions

The considerably increased electricity supply resulting from the construction of the new power station extension has enabled new development schemes to be fostered which will improve the facilities at both Port Fouad and Port Said.

Evidence of the rising standard of living and increase in population of the Isthmus is shown by the continuous expansion of the general building programme for the area. Industrial concerns represent almost half of the 6,000 commercial establishments in the Isthmus.

As a result of this rapid development, demands for power will eventually exceed the present installed capacity of the Port Fouad Station, and therefore, as previously mentioned, a further generating set is being installed.

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